BGC ENGINEERING USA INC.
AN APPLIED EARTH SCIENCES COMPANY

WESTERN FEDERAL LANDS HIGHWAY DIVISION

POLYCHROME AREA IMPROVEMENTS

GEOTECHNICAL MODELING REPORT

FINAL – REV 1

PROJECT NO.:	2000004	DATE:	March 29, 2022
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March 29, 2022
Project No.: 2000004

Brandon Stokes, Project Manager
Western Federal Lands Highway Division
610 East Fifth Street
Vancouver, WA 98661

Dear Brandon Stokes,

Re: Polychrome Area Improvements – Geotechnical Modeling Report - FINAL

BGC Engineering USA Inc. (BGC) is pleased to provide this report summarizing modeling work completed by BGC in 2022 to support Western Federal Lands Highway Division (WFLHD) and Jacobs Engineering, Inc. (Jacobs). We appreciate the opportunity to partner with WFLHD and Jacobs in this important work.

Yours sincerely,

BGC ENGINEERING USA INC.
per:

Heather Brooks, Ph.D., PE
Geotechnical Engineer

EXECUTIVE SUMMARY

BGC Engineering USA Inc. (BGC) prepared this report to present the results of two distinct numerical modeling efforts as described below, and to provide recommendations to inform the Design-Build Request for Proposal (RFP), design and construction, and longer-term monitoring. The modeling was performed is as follows:

1. Three-dimensional (3D) thermal modeling of the East Bridge Abutment area to:
   a. Analyze whether projected future climate conditions will degrade the ice-rich permafrost underlying the east bridge abutment; and,
   b. Evaluate potential requirements to maintain permafrost in this area.
2. Two-dimensional (2D) numerical thermal, deformation and stability modeling of the Pretty Rocks Landslide under current conditions and the additional load from potential rock cut spoil placement, both under current climate conditions and 2100 climate projections to:
   a. Analyze the thermal, deformation and slope stability condition of the Pretty Rocks Landslide in consideration of climate change conditions and placement of spoil on the landslide;
   b. Develop criteria for the timing, amount and location of spoil placement such that placement is not likely to materially alter the dynamics of the slide;
   c. Develop relative means for assessing potential impact of spoil placement on the landslide to evaluate alternatives; and,
   d. Provide recommendations for performance monitoring and spoil placement criteria to be met during construction.

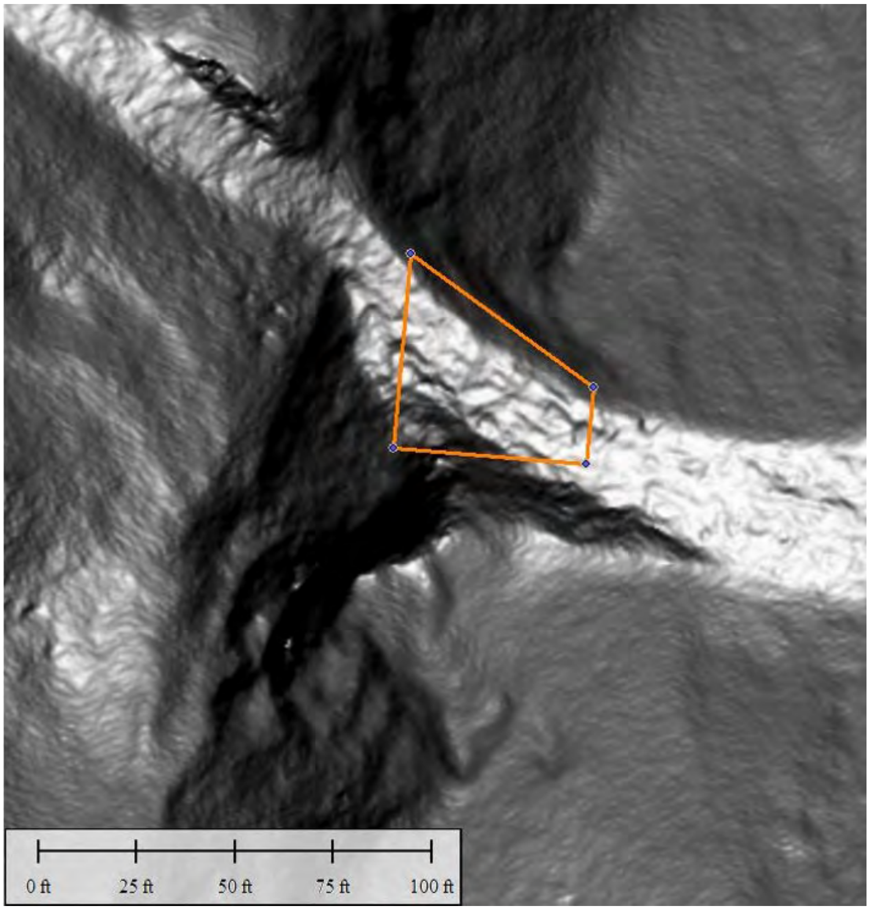
The analyses represent simplifications of a complex natural condition of landslide deformation and permafrost degradation, as characterized by the limited site investigations that were performed, and the monitoring sensor data available at the time of analysis. In addition, the analyses reflect a projection of changing climate conditions that introduce other uncertainty. Consequently, the results have their own considerable uncertainty, and are useful primarily for comparisons of alternatives that have been evaluated in the same way, and not for absolute predictions. The comparisons have been used to make recommendations to inform the RFP, project design and construction, and longer-term monitoring.

East Bridge Abutment 3D Thermal Model

BGC developed a 3D thermal model using Temp3D and Leapfrog software. The model was calibrated to the existing climate, and subsurface and ground surface characteristics. This was done using ground temperature data from borehole PR19-07 and stratigraphy of this borehole and others nearby. The temperature data show a constant near 32°F temperature with depth, typically indicating a degrading permafrost condition. The subsurface data from boreholes indicates that in the rhyolite that forms the small topographic abutment ridge, and below, permafrost is present and, where soil-like clay material is present, is ice-rich, and subject to softening and weakening as a result of permafrost degradation. These observations, in combination with the dip of the geologic structure, expectation of a warming climate, suggest that, if permafrost degradation continues, scarp oversteepening and retrogression in front of the abutment, settlement and shear strains beneath the abutment are potential risks to the long-term bridge performance.

Modeling was used to evaluate this condition and, thermally, how it might progress under current climate change projections, and to evaluate the possibility of arresting permafrost degradation in a 3D subsurface region where the strength and stiffness of frozen material will be required bridge abutment. The topography of the model was altered to reflect the development of a scarp west of the planned East Bridge Abutment. Using CMIP5 RCP8.5 climate projections to 2060 to 2080, the modeling suggests degradation progressing from the active layer thickness of 6 ft to a talik that extends to approximately 100 ft below ground surface. To mitigate the permafrost degradation, and the consequences from it, alternatives to cool a portion of the abutment area were modeled. The results show that it is practical to passively cool a portion of the abutment area in today's climate, and well into the future.

BGC recommends thermosyphon evaporators be placed in a defined prism (Schematic ES-1) and be designed to cool the subsurface interval between elevation 3520 ft and 3570 ft to 28°F within this prism. The design climate conditions should be the 2060 to 2080 CMIP5 RCP8.5 projections. The design should be adaptive to allow increased condenser section size, should additional cooling capacity be required in the future. Condensers should be co-located on the south side of the road, protected from traffic and potential rockfall. BGC recommends that these requirements be included in the RFP. The installation of ground temperature monitoring is also recommended. It would be designed and installed as part of the project and should be monitored after project completion to confirm satisfactory performance and provide early detection if modifications are needed.

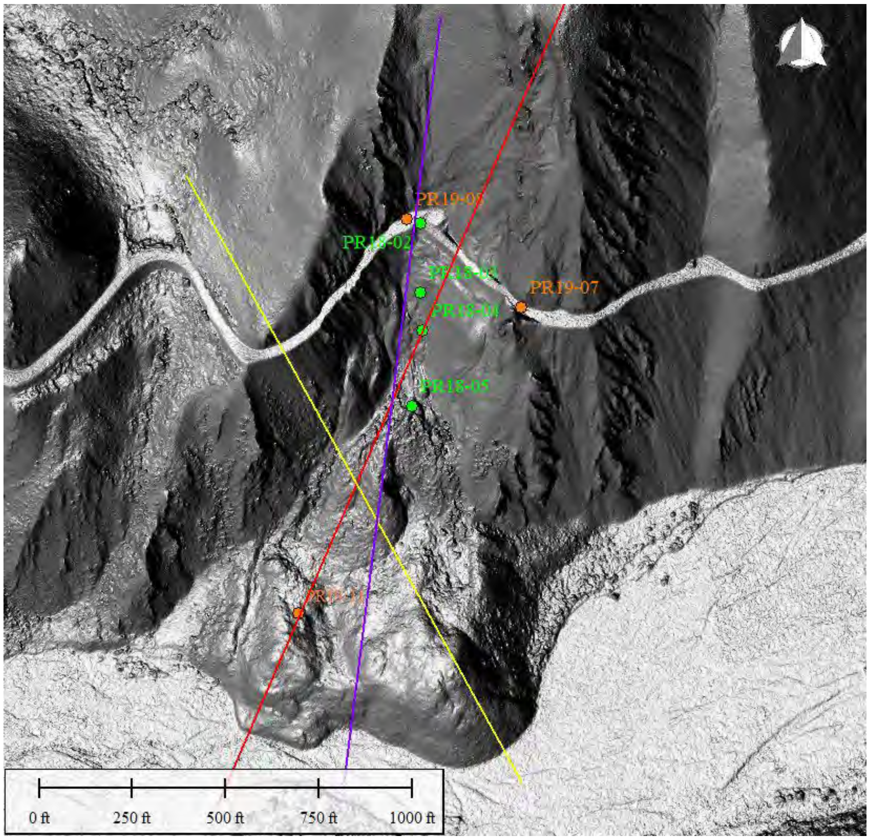


Schematic ES-1. Location of 28°F area (El. 3570 ft – 3520 ft) at the East Bridge Abutment.

Spoil Placement Modeling

BGC understands that it is desired for the rock cut spoil (111,165 cubic yards, plus bulking from excavation) to be placed on Pretty Rocks Landslide. The spoil is generated from cuts on both sides of the proposed bridge, but primarily west of the bridge, and its placement should be done in such a way that it does not materially alter the character of landslide movement that is anticipated without spoil placement. To evaluate the potential for this and identify constraints, BGC developed 2D models at the locations in Schematic ES-2 including thermal models in Temp/W, deformation models in SIGMA/W, and slope stability models in SLOPE/W software. These models are interconnected but not coupled, meaning that the output from one is readily used in another, but there is no feedback loop. These models were used to analyze three scenarios of spoil placement:

- Scenario 1 (S1) – The entire spoil volume is placed below the road on the middle section of Pretty Rocks Landslide, approximately centered around PR18-04 and -05.
- Scenario 2 (S2) – The entire spoil volume is placed near the toe of Pretty Rocks Landslide centered on the approximate distance from toe to PR19-11.
- Scenario 1/2 (S1/2) – Approximately half of the spoil volume is placed in a similar location to S1 and the other half is placed in a similar location to S2.



Schematic ES-2. Plan view of the site (2021 DEM) with analysis cross-sections.

The thermal models were calibrated with available ground temperature data from 2018 and 2019 boreholes, and historical climate conditions. The ground thermal regimes from these models define the likely extents of the permafrost along the cross-sections investigated, which were then used to help define the strength and deformation properties for the deformation and slope stability models in section.

The deformation models were calibrated to have similar deformation behavior, not deformation magnitude, to the Shape-Accel-Array (SAA) data. Groundwater was considered in the deformation model to be consistent with observations from vibrating wire piezometer data and site understanding to inform consolidation response in the deformation model. The ground stresses obtained in the deformation models, after thermal calibration and calibration to the SAA data, were subsequently used in the slope stability modeling to determine the potential slip surfaces and factors of safety due to spoil placement for all scenarios.

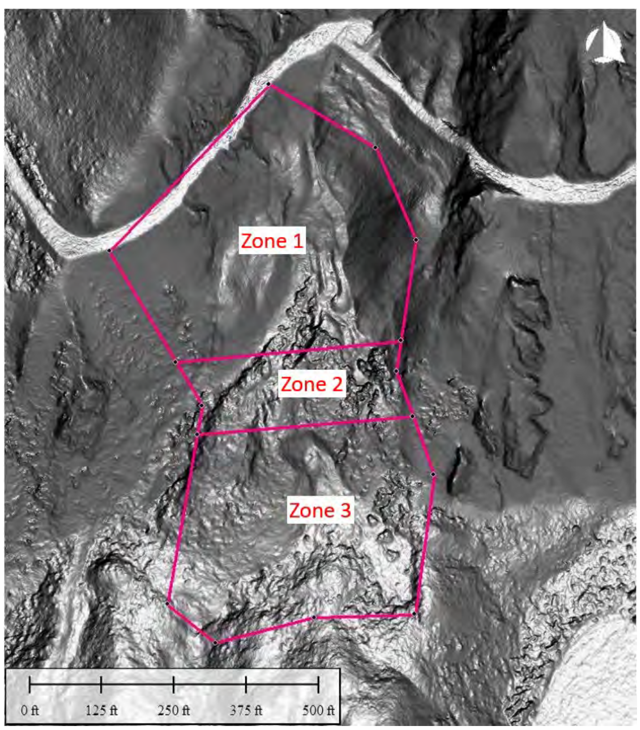
To investigate the long-term stability of the spoil, these models were re-analyzed using the 2080-2100 CMIP5 RCP8.5 climate projection. Thermal modeling under this climate projection shows the spoil acts as a thermal insulator at locations where it is placed on the Pretty Rocks Landslide. The permafrost aggrades into the expected spoil placement locations but continues to degrade at locations without it. The change in thermal regime over the climate projection time scale consequently changes the permafrost delineation in the deformation and slope stability models. These changes were accounted for by updating the deformation and stability models to the ground thermal regime observed in the 2080-2100 climate projection.

The model results show that in the current climate conditions the S1/S2 scenario does not reduce the factor of safety for the failure modes analyzed and it results in less deformation than either the S1 or S2 scenarios in the regions where the spoil is placed. These results suggest that deformations will occur because of spoil placement, but they will not be materially different from what has been occurring and what could be expected without spoil placement. When considering the climate projections for the year 2100, a greater amount of deformation is expected per the model results, but it is still less for scenario S1/S2 than the other scenarios and not materially different than what would be expected without spoil placement.

Therefore, model scenario S1/S2 is deemed to represent an acceptable location for spoil placement. Informed by these results, BGC recommends placement of spoil within a polygon that has greatest depth in the S1/S2 locations, and a requirement for more spoil placed lower on the slope than higher (Table ES-1, Schematic ES-1).

Table ES-1. Maximum fill depths at spoil area zones on Pretty Rocks Landslide.

Zone	Max Fill Depth (ft)
Zone 1	35
Zone 2	20
Zone 3	60



Schematic ES-3. Recommended spoil area delineation.

Because of uncertainties in the modeling and the climatic conditions during spoil placement, BGC recommends a monitoring program be put in place, and that a trigger-action-response-plan (TARP) be developed and followed so that spoil placement can be modified if movement is greater than anticipated. Additionally, BGC recommends longer-term monitoring be planned to observe landslide behavior after project completion.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF PHOTOGRAPHS

LIST OF SCHEMATICS

LIST OF FIGURES (appended)

LIST OF APPENDICES

LIMITATIONS

BGC Engineering USA Inc. (BGC) prepared this document for the account of Western Federal Lands Highway Division. The material in it reflects the judgment of BGC staff in light of the information available to BGC at the time of document preparation. Any use which a third party makes of this document or any reliance on decisions to be based on it is the responsibility of such third parties. BGC accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this document.

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1.0 INTRODUCTION

BGC Engineering USA Inc. (BGC) has been retained by Jacobs Engineering Group Inc. (Jacobs) to perform geotechnical modeling in support of design and construction of the Polychrome Pass Area Improvements in Denali National Park and Preserve, Alaska (DNP).

BGC has performed this work under Subconsulting Agreement No. 148025567 Task Order No. 148032710, with Jacobs and their Contract No. 69056721D000007, Task Order No. 69056722F000017 with Western Federal Lands Highway Division (WFLHD).

1.1. Background

The concept of a bridge spanning the Pretty Rocks Landslide, and rock cuts on either side of the bridge for construction access and improved roadway geometry, has been developed by WFLHD at a feasibility level. The conceptual design of the Polychrome Pass Area Improvements includes the following primary geotechnical aspects:

1. Deep foundation at each abutment to be founded in competent rock;
2. East bridge abutment rock cut;
3. Western abutment and approach rock cut to provide appropriate turning space for vehicles utilizing the bridge; and,
4. Mitigation of the Perlite Landslide.

BGC completed a geotechnical site investigation in support of the project in 2021 (BGC, 2022, February 25). In October 2021, WLFHD and DNP determined that the project will be delivered via a Design-Built contract. BGC understands that any project rock cut spoil is intended to be placed within the footprint of the Pretty Rocks Landslide, considering delineated wetland areas, during the project construction (NPS, 2022).

1.2. Scope of Work

In support of the design and construction of the proposed bridge, BGC prepared this report to outline the results of two distinct, but interconnected, numerical modeling efforts:

i) a thermal model of the east bridge abutment, and
ii) a combination of thermal, stress, and stability model of the Pretty Rocks Landslide under the additional load from potential spoil placement.

The first modeling effort, hereafter discussed as the East Bridge Abutment Modeling, includes the development of a three-dimensional (3D) geothermal model of the subsurface and thermal regime in the vicinity of the east abutment to determine potential implications from permafrost degradation and provide the requirements of a long-lasting functional structure. The objective of this scope is to:

1. Analyze whether projected future climate conditions will degrade the ice-rich permafrost underlying the east bridge abutment; and

2. Evaluate potential requirements needed to maintain permafrost in the foundation of the east bridge abutment with a changing climate.

The second modeling effort, hereafter discussed as the Spoil Models, includes the:

1. Development of a combination of thermal, stress-state and limit equilibrium models that includes consideration of permafrost creep and climate conditions for an extended time post-construction.
2. Development of criteria for the timing, amount, and location of material placement of the potential spoil generated during construction such that the placement is not likely to materially alter the natural dynamics of the slide.
3. Provision of a relative means for quantifying the impact of placement such that alternatives can be evaluated against one another. The analysis focuses on locations where acceleration of the slide may detrimentally impact conditions at the location of key structural elements of the project or the width of the river channel.
4. Provision of recommendations for performance monitoring and criteria that would be advised to be met during construction.

An important consideration is that the Pretty Rocks Landslide is active (BGC, 2022, February 25) and any change in loading and/or thermal conditions (e.g., spoil placement) may alter on-going movements. The placement of the spoil at any location along the landslide will alter its current thermal state and will consequently impact the mechanical stresses in both near-term and long-term conditions that govern deformation and slope stability conditions. An understanding of how the thermal regime changes due to the location spoil placement can help inform understanding of possible consequences over time. This effort is to aid in understanding the effects of the spoil placement, including locations and quantities, to evaluate potential impacts to the landslide and provide monitoring recommendations. The complexity of the geophysical processes and the thermo-hydro-mechanical responses of the materials, combined with the limited in-situ information available results in limited capacity of representing actual deformations with time in the numerical models. Therefore, BGC focused on interpreting the relative changes in the response of the numerical models due to changes in boundary conditions, such as climate and/or loads, rather than the absolute values.

This report documents the methodology, results, and recommendations for these scopes of work. Detailed information on the landslide is not included in this report as those are available in documents previously completed (Section 1.3). Recommendations for specifications that may be useful for procurement or execution of the work, and for monitoring of these project aspects are also included.

1.3. Previously Completed Work

Information from previous geotechnical work within the Pretty Rocks Landslide is included in the following reports and memoranda prepared by (or for) WFLHD.

- Western Federal Lands Highway Department (March 10, 2020). Geotechnical Memorandum 10-20 (WFLHD GM 10-20): Pretty Rocks Landslide Rockfall Analyses, Pretty Rocks Landslide Repair AK NPS DENA 10(50), WFLHD Geotechnical Section.
- Western Federal Lands Highway Department (March 23, 2020). Geotechnical Memorandum 03-20 Revised (WFLHD GM 03-20): Pretty Rocks Landslide Bridge Feasibility and Constructability, Pretty Rocks Landslide Repair AK NPS DENA 10(50), WFLHD Geotechnical Section.
- Western Federal Lands Highway Department (April 20, 2020). Geotechnical Memorandum 14-20 (WFLHD GM 14-20): Pretty Rocks Landslide Earthwork Feasibility and Constructability, Pretty Rocks Landslide Repair AK NPS DENA 10(50), WFLHD Geotechnical Section.
- Western Federal Lands Highway Department (August, 2020). Geotechnical Report No. 11-20 (WFLHD GR 11-20): Pretty Rocks Landslide 2018-2019 Geotechnical Investigation and Conceptual Design Alternatives Report AK NPS DENA 10(45), WFLHD Geotechnical Section.
- BGC Engineering USA Inc. (August, 2020). Geotechnical Report 05-20, AK NPS DENA 10(49), Geotechnical Summary Report of Existing Conditions. Prepared for Western Federal Lands Highway Division, Federal Highway Administration, FHWA.
- BGC Engineering USA Inc. (May 19, 2021). Geotechnical Memorandum 14-21, AK NPS DENA 10(49), Polychrome Area Improvements – Preliminary Geotechnical Memorandum. Prepared for Western Federal Lands Highway Division, Federal Highway Administration, FHWA.
- BGC Engineering USA Inc. (February 25, 2022). Polychrome Area Improvements, Geotechnical Data Report – Final. Prepared for Western Federal Lands Highway Division, Federal Highway Administration, FHWA.

1.4. Structure of this Report

This report documents both scopes of work discussed in Section 1.2. Where possible, data and methodologies used in both scopes are presented together to avoid duplication in Sections 2.0, 3.0, and 4.0. Sections 5.0 and 6.0 discuss modeling activities specific to the Spoil Placement. Recommendations following from the analyses documented herein are presented in Section 7.0.

2.0 GEOTHERMAL MODELING – METHODOLOGY

Thermal modeling was conducted for the East Bridge Abutment and Spoil Models. After developing the model cross sections and calibrating the model with thermistor data available from the site until April 2020 (BGC, 2022), the models were analyzed considering climate change projections. The commercially available TEMP/W and TEMP3D programs of the GeoStudio 2021.4 software suite (Version 11.3.0.23668) were used to perform the thermal numerical analyses.

2.1. Modeling Basis and Limitations

2.1.1. Model Basis

The thermal modeling completed is based on the data available to BGC in January 2022. Ground thermo-hydro-mechanical properties and climate interaction were simplified or adjusted to reach conditions that will match those from measured temperature data at the site (model calibration).

2.1.2. Modeling Limitations

Numerical modeling is based on various assumptions and has several limitations depending on the local conditions and models used. Limitations for all the analyses presented herein include but are not limited to, model conditions, n-factor, and model validation. Limitations on these factors are discussed below.

- The constant model geometry has an effect on the geothermal model. Settlement through thaw consolidation will occur as the permafrost degrades but the model geometry remains constant. This affects the analysis by providing results with thinner active layer thicknesses in the model compared with what is expected should the thaw consolidation be taken into account. The thermistor readings are therefore relative to their original location of installation which may have shifted as the landslide continues to advance. Additionally, continued deformation of Pretty Rocks Landslide is expected; thus, the geometry of the landslide will change through time. Therefore, the continual evolution of the permafrost conditions within the landslide mass as deformation occurs has not been explicitly modeled.
- The n-factor is an aggregate factor which relates air temperature to ground surface temperature. The model parameters and n-factors are calibrated to match measured site ground temperatures. The n-factors are assumed to be constant throughout the model time, which is a significant limitation, specifically during the winter. The snow thickness and its density influence the accuracy of the model's n-factors during the winter months. There may be less snow accumulating on the ground in the future, potentially resulting in colder ground temperatures and thinner active layer. Or there may be more snow, resulting in other impacts to the assumption of this parameter as constant.
- A more sophisticated approach is available (e.g., Surface Energy Balance) that accounts for several parameters (e.g., air temperature, albedo, relative humidity, precipitation, windspeed, snow thickness, solar radiation) to transform air temperatures to ground

temperatures. With the inherent uncertainty in the climate change models, that are still at a regional scale, and limited local climate data, it was considered inappropriate to add additional complexity to the analyses presented herein. The primary driver of ground temperature change is still the change in air temperature, which has been accounted for in the numerical model.

- Thermal modeling time scales for climate projections are relative trends and do not reflect real time conditions.
- The simplification of temperature over time does not account for extrema nor changes to climate projections in the future. Extrema consist of periods that are extremely cold or extremely hot. Such short-term extrema are considered to not have any significant impact on the relevant modeled temperature results as they mainly affect shallow ground temperatures for a limited time, but not the ground thermal regime in its larger context.
- Undrained loading conditions due to spoil placement are not modeled, yet in some instances undrained loading may influence the landslide behavior. The permafrost in the landslide is, by definition, geologic material that is cryotic (< 32°F) for at least two consecutive years. Depending on the porosity, type, chemistry, and temperature of the material, not all of the pore moisture may be ice. Water can flow through the unfrozen portion of the pore space, and this partially frozen material, and will have a corresponding increase in pore water pressure. On-going active slide movements and any additional loading (i.e., spoil placement) on top of the landslide may therefore impact pore pressures in ways that have not been captured in the model. Additionally, there are limited groundwater monitoring instruments at the site and, where they are present, they are outside the footprint where the spoil will likely be placed.
- The actual behavior of the landslide involves complex physical processes (e.g., freeze-thaw action, creep, ground ice melting, thaw consolidation, groundwater flow, etc.) that cannot accurately be captured without additional site data and using more sophisticated, research-type numerical tools. Several assumptions and simplifications have therefore been made for all analyses, which are supported by model calibrations and sensitivity analyses prior to conducting spoil placement and climate change modeling.

2.2. Model Cross-Sections

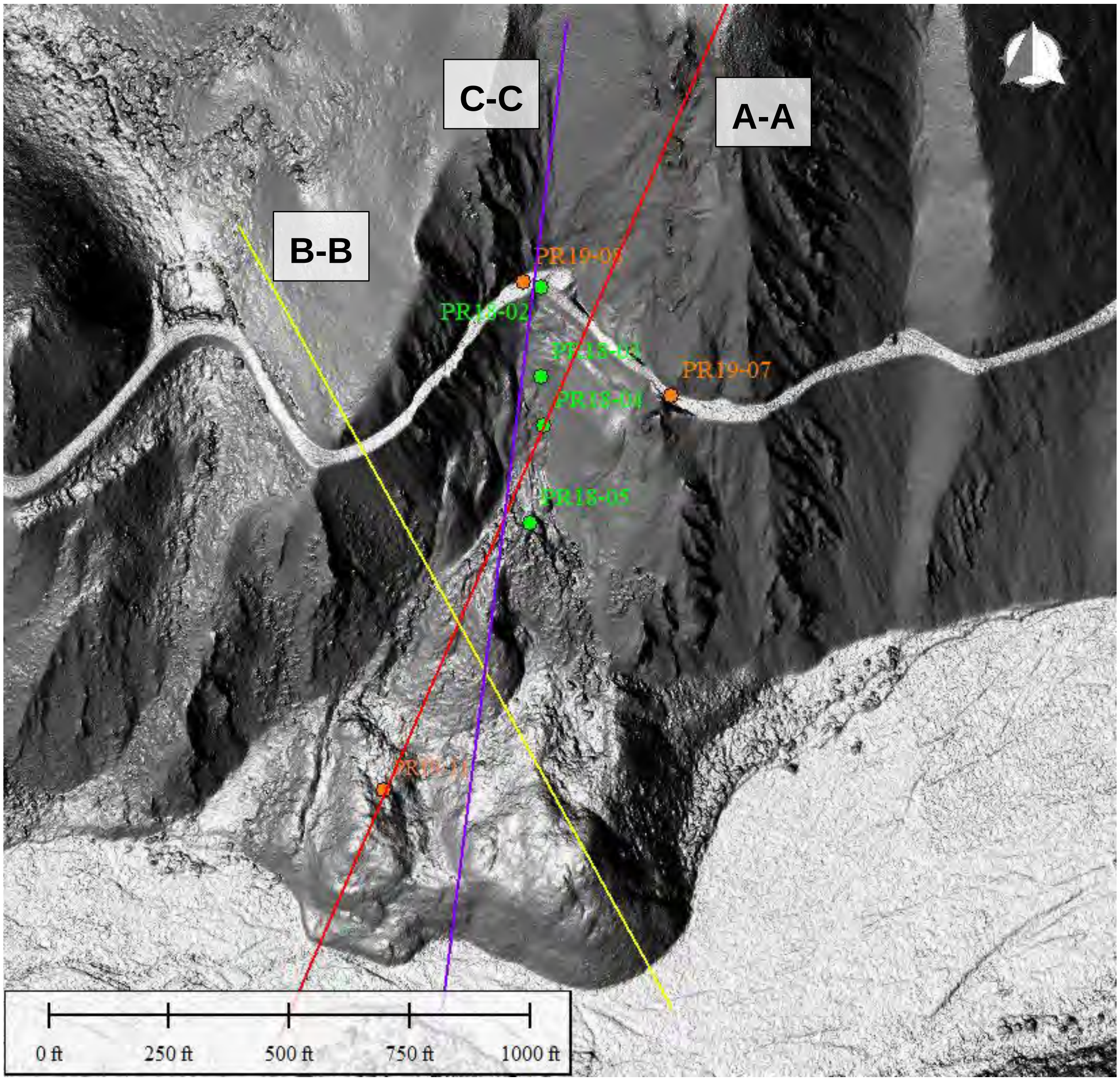
2.2.1. Spoil Model

To determine the varied effects of the spoil placement, three cross sections were considered for the two-dimensional (2D) Spoil Model. The September 1, 2021 digital elevation model (DEM) provided by DNP was used to develop the model geometry (Schematic 2-1) and site data to assign various materials. Section A-A passes through nearby boreholes PR18-04 and PR19-11, which are both within the footprint of the landslide. Section C-C passes through nearby boreholes PR18-02 and PR19-08 at the west end of the original roadway alignment. The locations of PR18-04 and PR19-11 relative to Section C-C were approximated for comparison of temperature results. Section B-B was chosen as an intermediate section in the analysis, but no nearby boreholes were available along this section. The cross-sections shown in Schematic 2-2 were developed in TEMP/W based on topography of the site and the stratigraphy inferred from the nearby borehole logs. The approximate borehole locations are shown as vertical orange lines in Schematic 2-2 and Schematic 2-4.

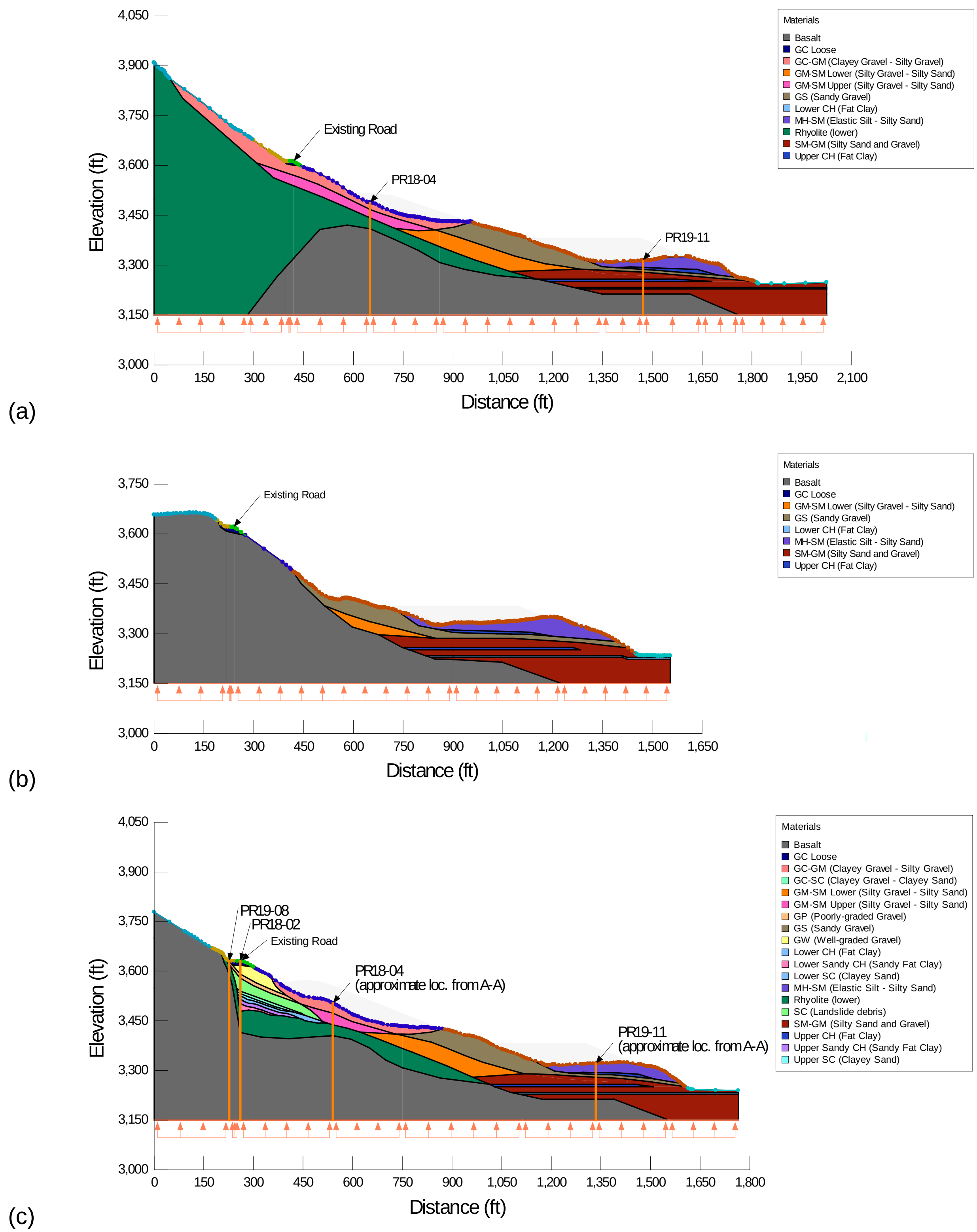
Preliminary design estimates for the project show a rock cut volume of 3.0 million cubic ft (111,165 cubic yards) (Yeoman, January 6, 2022). Some bulking of these material would be expected during removal, transport and placement activities. For the purpose of the modeling, the spoil is assumed to be placed at one of two locations, and an intermediate scenario is also considered:

1. Spoil would be cast on to the slope below the road to the southwest of the planned west abutment location; and
2. Spoil would be placed onto the relatively flat bench that is present on Pretty Rocks Landslide between the steep angle section at mid-slope and the crest of its sloped toe, to where it meets the East Fork Toklat River.

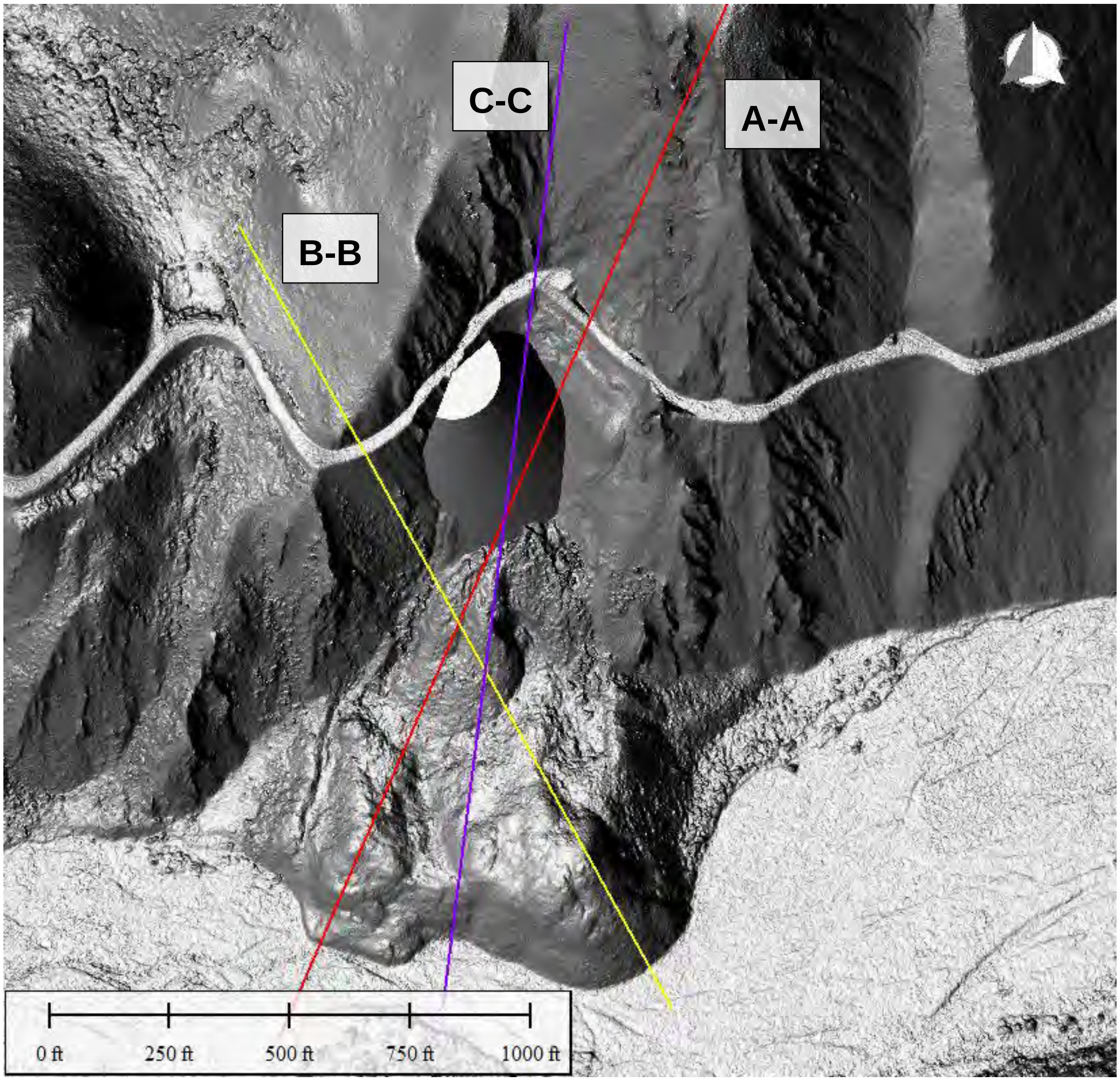
For the first Scenario (S1), it is assumed that a 100 ft platform of spoil would result from spoil placement and material rolling downslope at an assumed angle of repose equivalent to 35° as shown in Schematic 2-3. The equivalent volume of this spoil is 4.3 million cubic ft (159,260 cubic yard). Between Section A-A and Section C-C, Section C-C has a larger equivalent mound in 2D and is the cross-section primarily presented and discussed in this report. Results for Section A-A are provided in Appendix B. Two alternative spoil placements were considered: Scenario 2 (S2) where all of the spoil is placed at the toe of the landslide, as previously discussed, and an intermediate spoil placement scenario that splits the total volume between the two scenarios (S1/S2). These additional scenarios are shown in Schematic 2-4 for Section C-C. The maximum extent of the spoil allowed at the toe of the landslide is based on wetland delineation that was provided via email on February 23, 2022 (Garich, 2022) as shown in Schematic 2-5, which is significantly less than the area of S2 investigated in the numerical model. Additionally, the Material Placement Area does not extend as far onto the toe of Pretty Rocks Landslide as the spoil placement extent used in Scenario S2. Scenario S2, therefore, presents a case where loading at the landslide toe is greater than expected during construction.



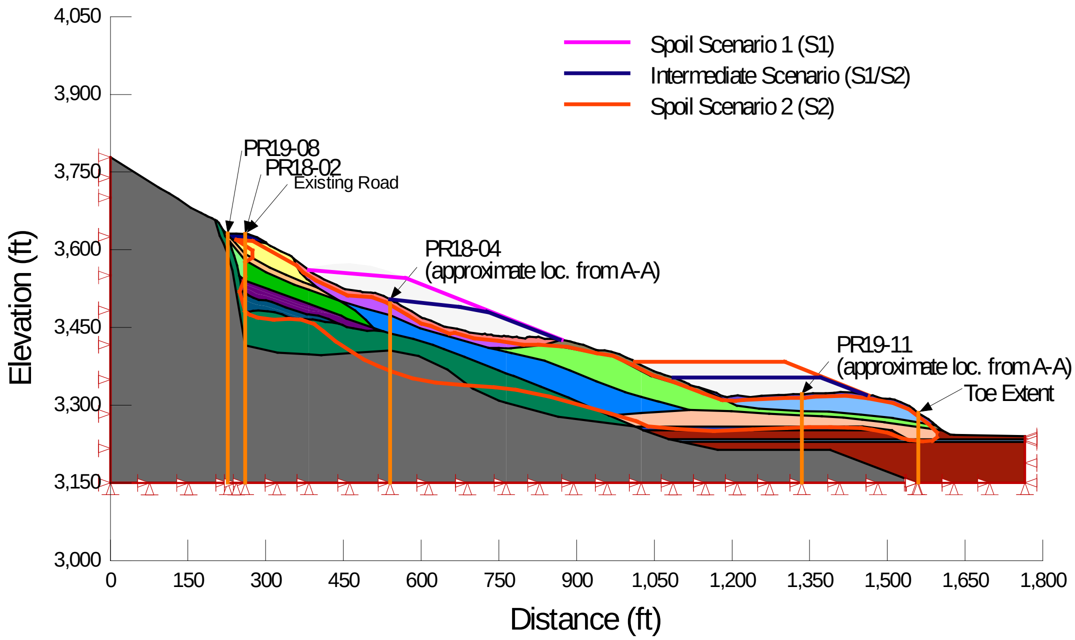
Schematic 2-1. Plan view of the current site based on 2021 DEM model with analysis cross-sections.



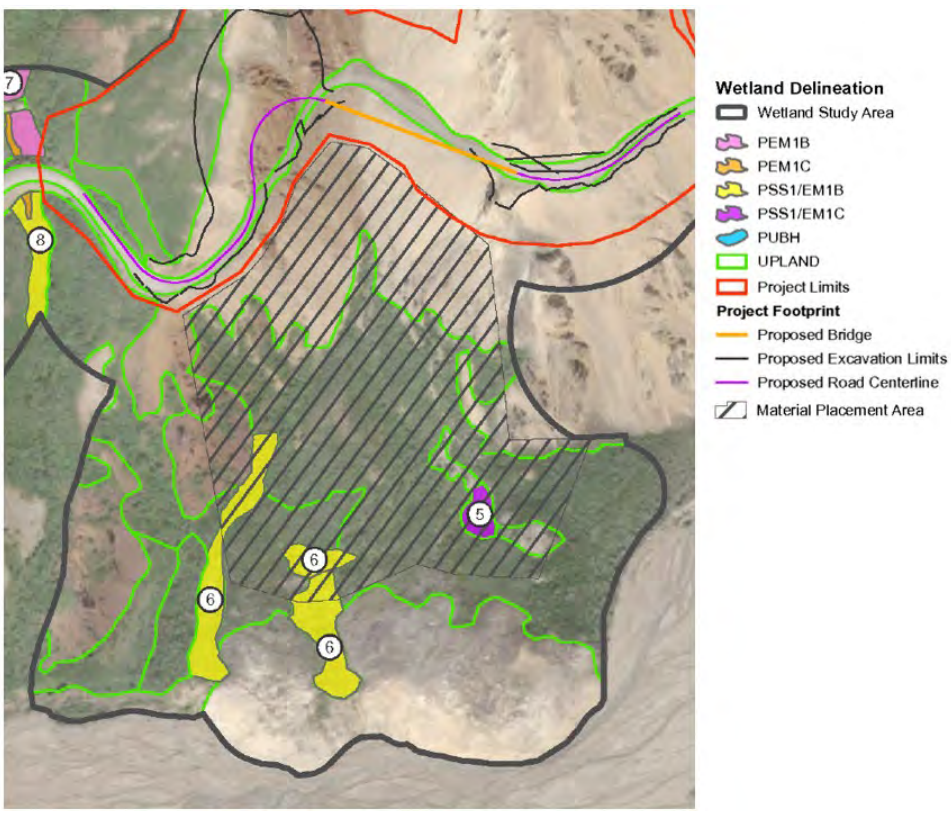
Schematic 2-2. Cross-sections for (a) Section A-A, (b) Section B-B, and (c) Section C-C showing interpreted materials and approximate borehole locations. Geothermal heat flux shown as uniform vertical orange arrows along the base of the model.



Schematic 2-3. Current site with superimposed spoil placement of Scenario 1 (S1).



Schematic 2-4. Cross section C-C with superimposed soil placement for Scenarios 1 (S1), 2 (S2), and the Intermediate Scenario (S1/S2).

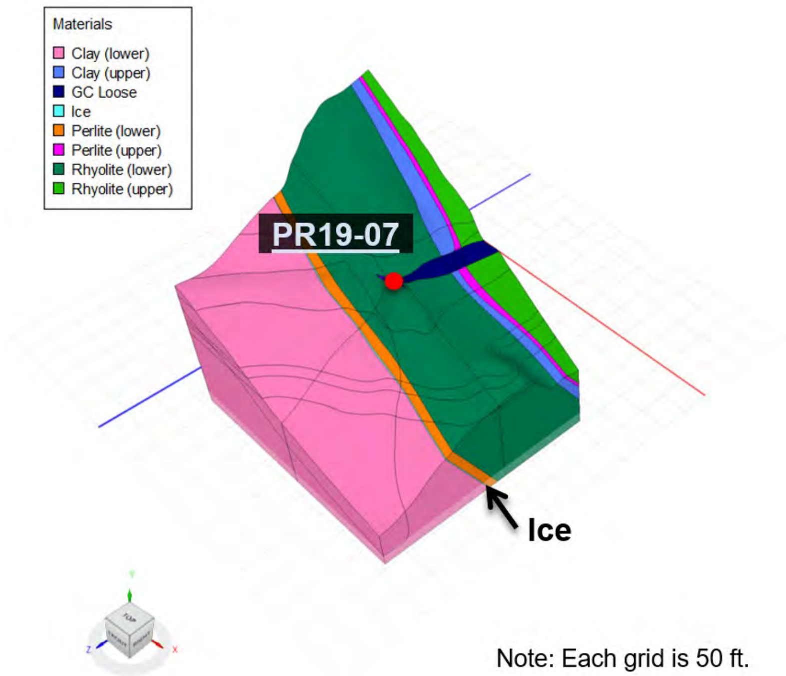


Schematic 2-5. Approximate limit of wetlands and material placement area. Drawing provided by Garich (2022) via email.

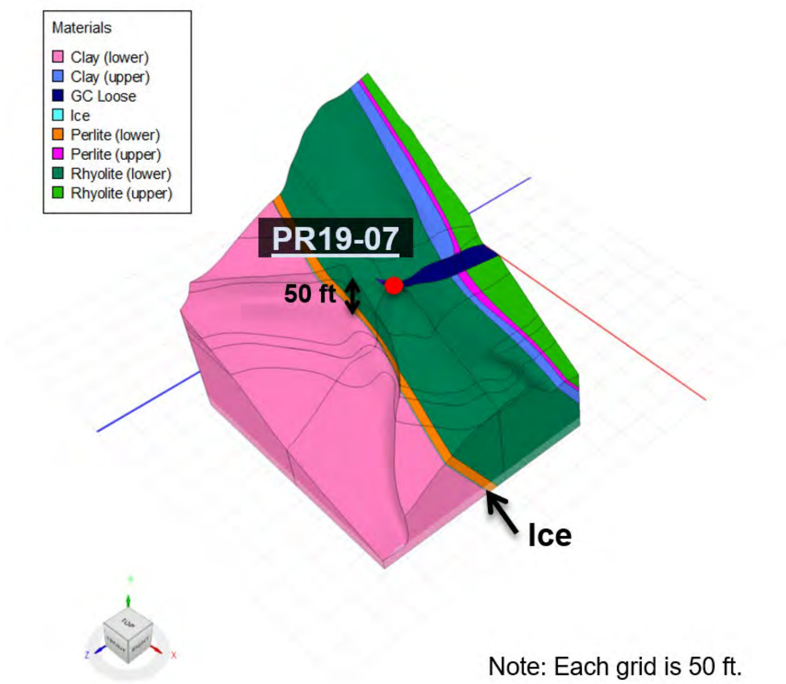
2.2.2. East Bridge Abutment Model

The 3D section in TEMP3D is shown in Schematic 2-6a with a simplified stratigraphy based on borehole PR19-07 from 2019, boreholes PR21-01, PR21-02, PR21-07, and PR21-08 from the 2021 field campaign (BGC, February 25, 2022), surficial geologic mapping, and BGC's understanding of the site. The topography is from the 2021 digital elevation model (BGC, February 25, 2022). The software Leapfrog Works 2021.2.4 (Seequent Limited, 2021) was used to develop the 3D simplified interface between each soil, rock, and ground ice unit. It is recognized that this model simplification does not fully encapsulate the complex lithology of the rock layers nor the complex stratigraphy of the soil layers, but reasonable approximations were made based on borehole data available at this location. Thermistor data is only recorded at PR19-07 to a depth of 30 ft from the ground surface and was used as a reference point in sectioning the model.

Site photos (Photograph 2-1) were provided to BGC on January 31, 2022 (Capps, 2022) which show additional drop in elevation from the original road alignment near the planned east bridge abutment location. This was accounted for in TEMP3D by removing 50 ft of material from the topography used from the original analysis as shown in Schematic 2-6b. The material removed from the model was assumed to be completely mobilized and deposited outside the domain of the model. This material removal exposes the soil and rock units closer to PR19-07, which changes the thermal regime at the east abutment.

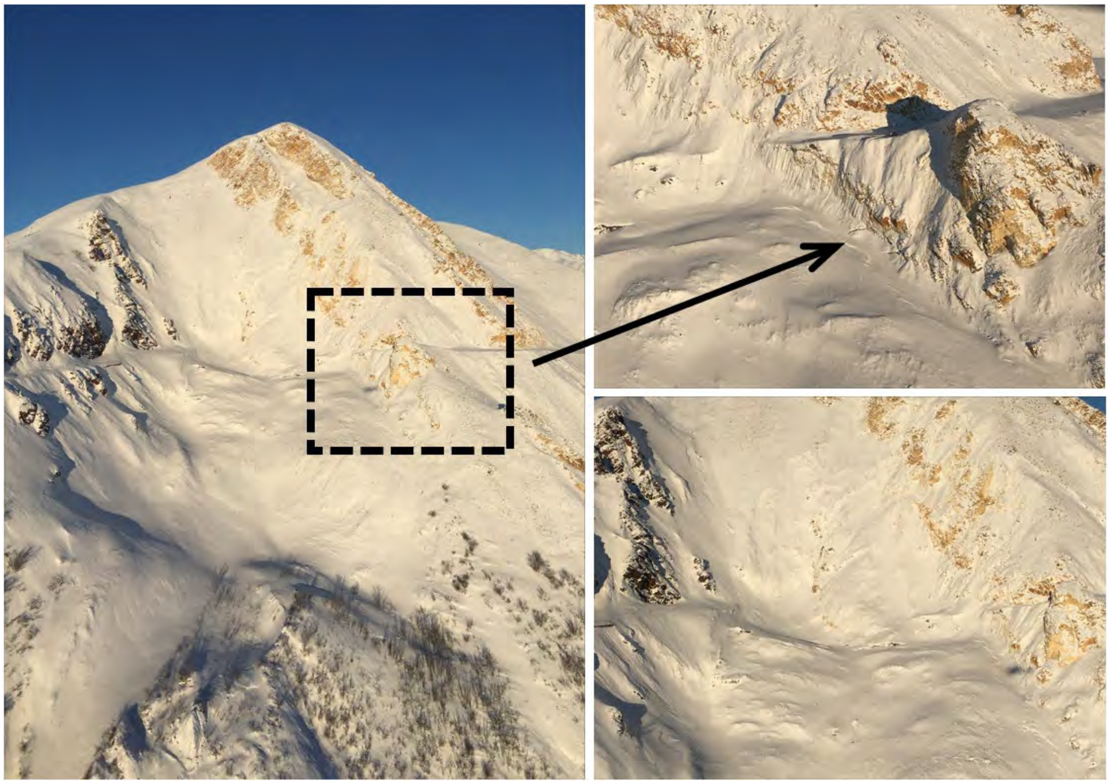


(a)



(b)

Schematic 2-6. East abutment 3D section in TEMP3D: (a) Original section using the 2021 DEM model and (b) removal of landslide material based on January 31, 2022 conditions.



Photograph 2-1. Site photos taken by Lance Williams on January 31, 2022 showing landslide progression (Capps, 2022).

2.3. Boundary Conditions

Historical climate data (i.e., air temperature) recorded at the McKinley Park weather station (Latitude: 63° 43' 48" N, Longitude: 148° 54' 36" W) between 2010 and 2020 was used for model calibration. A sinusoidal function was fitted to this historical climate data and adjusted to match the overall trend between this period. It was assumed that the average temperature from this sinusoidal function is representative of the air temperature conditions that resulted in the ground temperature data measured at the site. The sinusoidal function for the historical climate data is shown in Figure 2-1. The temperature boundary is applied and cycled for at least 5 years to attenuate the ground temperatures throughout the model. The assumed temperature of water from the East Fork Tolkat River at the toe of the landslide is also shown in Figure 2-1; this is the boundary condition used through the river valley south of the Pretty Rocks Landslide toe.

A geothermal heat flux of 0.0253 BTU/hr/ft^2 (approximately 80 mW/m^2) was used along the base of the model based on the heat flow map of Alaska (Batir et al., 2013) for the project location. This boundary condition is shown as uniform vertical arrows in Schematic 2-2. The sensitivity of the model to this geothermal heat flux was evaluated by varying the heat flux by +/- 5 mW/m^2 from the base case and running the models. The model results showed that the best fit with the thermistor data was obtained using the base case. For the initial, steady-state thermal condition, a mean annual air temperature (MAAT) of 31°F was applied throughout the ground surface. The recorded temperatures at PR18-04 and PR19-11 (for Section A-A), and PR18-02 and PR19-08 (for Section C-C) were used in establishing the initial conditions of the models. Once the initial condition was established, these temperature boundary conditions were removed for subsequent analyses.

The n-factor approach was used to convert air temperatures to ground surface temperatures. As shown in Figure 2-2 for the 2D sections, the n-factor applied to the model varies at different sections of the cross-section due to different ground surface conditions (e.g., snow cover, vegetation, surface color, type of material, etc.). The surfaces with n-factors applied in the 3D section is shown in Figure 2-3. The freezing (n_f) and thawing (n_t) n-factors were based on typical values available from literature (Andersland and Ladanyi, 2004) and were adjusted accordingly to best reflect the recorded ground temperatures. The n-factors used for the 2D and 3D thermal models are summarized in Table 2-1. The labels on Table 2-1 are not reflective of any ground type but are only based on model geometry to facilitate the use of these factors and are not interpretive beyond what is used for model input. In all scenarios of the Spoil Models, the activation temperature of the spoil in the model (i.e., the temperature of the spoil when it is placed on the landslide) is 45°F.

Table 2-1. Summary of n-factors used for 2D and 3D temperature models.

Model	Label	Freezing: n_f	Thawing: n_t
2D	Above road – slope	1.40	0.55
	Road surface – upslope	1.30	0.20
	Road surface – downslope	1.40	0.60
	Lower slope	1.10	0.60
	Rock glacier	1.05	0.30
	On spoil	1.20	0.70
3D	Above road – slope	1.30	0.70
	Road surface	1.10	0.40
	Lower slope	1.10	0.60
	Rock glacier	1.05	0.30
	Outside glacier	1.10	0.50

Climate change conditions were evaluated to 2100 using the RCP8.5 model from CMIP5 (Taylor et al., 2011; Dufresne et al., 2013). Similar to the calibration boundary condition, a sinusoidal function was fitted through periods in time to reduce daily fluctuations in air temperature. The sinusoidal fit was batched every 20 years as shown in Figure 2-1. Preliminary model runs have indicated that the temperature conditions will remain stable after 5 years of temperature cycling in the model. The model is considered stable when the change in ground temperature year-over-year is less than 1°F (approximately 0.6°C). The underlying assumption in this approach is that the temperature within the 20-year period will not increase over that time. A step function was used such that after cycling through the first sinusoidal function (i.e., 2020-2040) and equilibrium is reached, the next sinusoidal function (i.e., 2040-2060) is applied at the end of the previous step and another period of cycling for 5 years is initiated. This was done until the last time step was reached (i.e., 2080-2100). The years 2040, 2060, 2080, and 2100 are of interest when evaluating the results.

2.4. Thermal Material Properties

The thermal properties used in the analyses are summarized in Table 2-2. In the absence of laboratory and field measurements of thermal properties for each soil and rock unit, thermal properties available from literature (Cermak and Rybach, 1982; Robertson, 1988; Fukusako, 1990; Andersland and Ladanyi, 2004; Waples and Waples, 2004a; Waples and Waples, 2004b; Ehlers, 2005; Mielke et al., 2017; Dalla Santa et al., 2020) and approximations using published correlations (Andersland and Ladanyi, 2004) based on descriptive information at the relevant boreholes evaluated in the landslide area (PR18-02, PR18-04, PR19-08, PR19-11), and the location of the east abutment (PR19-07) were used. Borehole logs are provided in Appendix A. Adjustments and modifications to some of the values presented in Table 2-2 were done to best represent the measured temperatures from the thermistors at these locations during model calibration. The thicknesses and spatial distribution of each soil unit was approximated from borehole data.

The unfrozen and frozen thermal conductivities are represented by k_u and k_f, respectively. The unfrozen and frozen volumetric heat capacities are represented by c_u and c_f, respectively. The material model in TEMP/W and TEMP3D accounts for how the thermal conductivities are treated in the analyses. For the *Full Thermal* option, the thermal conductivity and unfrozen water content vary with temperature between 28°F and 32°F. The default options available in TEMP/W based on the type of material (e.g., silty sand, sand) were selected. For the *Simplified Thermal* option, the thermal conductivity is assumed to be constant below (frozen) and above (unfrozen) 32°F. Rhyolite, basalt, and perlite were modeled using the *Simplified Thermal* option, and all soil layers were modeled using the *Full Thermal* option.

Table 2-2. Summary of thermal properties used in the 2D and 3D temperature models.

Material Name	Density (lb/ft^3)	In-situ VWC	w (%) *	k_u (BTU/hr-ft-°F)	k_f (BTU/hr-ft-°F)	c_{vu} (BTU/ft^3-°F)	c_{vf} (BTU/ft^3-°F)	Model
Basalt	162.30	0.40	10	1.56	1.56	25.0	25.0	Simplified
Rhyolite Lower	152.93	0.30	15	1.30	1.30	28.0	28.0	Simplified
Rhyolite Upper	152.93	0.50	15	1.40	1.40	27.0	27.0	Simplified
Perlite Lower	152.93	0.30	15	1.30	1.30	28.0	28.0	Simplified
Perlite Upper	152.93	0.30	15	1.30	1.30	28.0	28.0	Simplified
Waste Material	127.34	0.19	10	0.72	1.51	31.3	28.4	Full
Ice	57.24	1.00	---	1.28	0.32	28.3	28.3	Full
GC Loose	127.34	0.20	8	0.68	1.34	30.0	30.0	Full
GC-GM	95.51	0.26	20	0.59	0.84	29.5	25.5	Full
GC-SC	133.58	0.60	30	0.83	2.69	48.4	38.1	Full
GM-SM Lower	139.83	0.70	45	0.85	3.18	59.8	40.5	Full
GM-SM Upper	139.83	0.60	60	0.81	3.11	67.3	43.3	Full
GP	127.34	0.60	12	0.70	1.20	25.0	21.0	Full
GS	146.07	0.78	50	0.87	3.64	65.3	45.8	Full
GW	127.34	0.60	10	0.70	1.20	31.3	27.2	Full
Lower CH	133.58	0.50	30	0.89	1.39	45.8	38.5	Full
Lower Sandy CH	121.10	0.50	10	0.76	0.74	29.8	25.9	Full
Lower SC	133.58	0.60	10	0.75	1.84	32.9	28.6	Full
MH-SM	95.51	0.51	50	0.48	1.17	42.7	31.5	Full
SC Landslide Debris	89.26	0.60	18	0.54	0.67	26.4	21.5	Full
SM-GM	139.83	0.52	30	0.86	3.14	50.6	37.2	Full
Upper CH	101.75	0.61	60	0.51	1.39	49.0	24.7	Full
Upper Sandy CH	139.83	0.50	10	1.10	1.27	29.9	34.4	Full
Upper SC	107.99	0.60	30	0.67	1.39	39.2	30.8	Full

Notes: VWC – volumetric water content, k_u – unfrozen thermal conductivity, k_f – frozen thermal conductivity, c_{vu} – unfrozen volumetric heat capacity, c_{vf} – frozen volumetric heat capacity
* assumed gravimetric water content from borehole logs

3.0 GEOTHERMAL MODEL CALIBRATION

The numerical model was calibrated using local ground temperature data. Such a calibration included the variation, within reasonable limits, of material parameters and boundary conditions until the model was reasonably consistent with measured ground temperatures at the site.

3.1. 2D Spoil Model

The base models for Section A-A, Section B-B, and Section C-C are as shown in Schematic 2-2. The location of the boreholes with thermistors available for calibration are also shown. The calibration results for October 2018 and January 2019 for PR18-02 and PR18-04, and October 2019 and January 2020 for PR19-08 and PR19-11, are summarized in Figure 3-1 and Figure 3-2 for Section A-A and Section C-C, respectively. The slight difference between thermistor readings and model results near the ground surface is due to the complex interaction between air and ground surface conditions that was simplified with the use of n-factors, and the varied pore water quantities held in the active layer during to seasonal freezing and thawing cycles. The model results follow the trend of recorded thermistor temperatures and provide confidence that these models can be used to evaluate the impact of spoil placement on the thermal regime under climate change conditions (Section 4.1) and for the slope stability assessment (Section 6.2) of the existing landslide. The thermal results of Section B-B are not shown since the model temperature results at the toe of the landslide are similar to the two other cross-sections presented.

The locations of the boreholes and corresponding thermistor strings were considered static in the model; that is, these thermistor strings remain at the location when they were installed. PR18-02, PR18-04, and PR19-11 are all in the active zone of the landslide and the thermistor strings may shift in location as the landslide advances over time. Only limited ground water data are available from the active landslide zone and the change in pore water pressure condition, both in the frozen and unfrozen zone as the landslide progressed over the calibration period, was not considered in the numerical model.

3.2. 3D East Bridge Abutment Model

The 3D calibration results with PR19-07 for the east bridge abutment section is shown in Figure 3-3. Similar to the 2D sections, the slight difference between PR19-07 and model results near the ground surface is due to the complex interaction between the air and ground surface conditions that was simplified with the use of n-factors, and the varied pore water quantities held in the active layer during to seasonal freezing and thawing cycles. The model results follow the trend of recorded thermistor temperatures and provide confidence that this model can be used to evaluate the long-term condition of the underlying foundation of the bridge abutment and options for remedial measures should the permafrost continue to degrade. PR19-07 is only 30 ft deep, but model results indicate that the ground remains frozen to at least 100 ft below ground surface during this period. This is consistent with observations during drilling at borehole PR21-01, in which ice infill was observed in rock joints and ice-rich material and ice lenses in the clay at depths ranging from 84 to 91 ft below ground surface (Appendix A).

The latest temperature data at PR19-07 were from 2019 to 2020. The model temperatures with the landslide progression (see Schematic 2-5, Photograph 2-1) are shown in Figure 3-3 with slightly warmer temperatures at depth in April and July, as compared to the original calibrated model results. As the landslide progresses, soil is evacuated from the slope face where the east bridge abutment will be founded. This reduction in material exposes the slope face directly to the ambient air temperatures and may accelerate degradation of the frozen ground.

4.0 CLIMATE CHANGE THERMAL MODELING AND RESULTS

4.1. 2D Model Results – Spoil Area

The results of the three scenarios at different locations along Section C-C are shown in Figure 4-1, Figure 4-2, and Figure 4-3 at the Upslope, Midslope, and Toe locations, respectively. The Upslope, Midslope, and Toe locations are analogous to PR18-02, PR18-04, and PR19-11, respectively. The no spoil scenario (NS) was evaluated as the base case to understand the ground thermal regime of the rock glacier in response to climate change, should the spoil not be placed on the landslide. The spoil acts as a thermal insulator, and results show that in comparison with the NS case the placement of the spoil between the months of mid-August to mid-October for all three scenarios (S1, S1/S2 and S2) will keep the ground frozen and permafrost aggrades upwards into the spoil itself. Under climate change, the thickest spoil placement scenarios (S1, S2) resulted in the largest thermal regime change at their placement areas. The isotherms in October 2039, 2059, 2069, and 2099 are shown in Figure 4-4, Figure 4-5, and Figure 4-6 for each spoil placement scenario, respectively. These figures show that relative to the time and temperature of spoil placement, a talik (a region of non-cryotic ground in permafrost) may form between the interface of the spoil and the natural ground. This talik is expected to shrink over time and is only marginally visible by the end of the climate change analysis. The Toe location of the landslide is most susceptible to thermal effects of climate change, where the 6 ft surficial depth of thaw increases to approximately 18 to 22 ft by 2100 (see Figure 4-4 between 1200 and 1600 ft along x-axis). The model temperatures on the slope above the existing road are warmer compared to Midslope and Toe locations because of the freezing and thawing n-factors used at the slope ground surface and the thermal conductivity of the soil and rock units.

The thermal conditions by 2099/2100 were used to delineate the frozen and unfrozen zones of the landslide. The delineation is used in the deformation and stability modeling to inform material properties to use in the analyses and will be presented and discussed in Section 6.0. The model temperature results for Section A-A show the same behavior for these observation locations as Section C-C considering the three spoil placement scenarios. The model temperatures with depth are shown in Figures B-2 to B-4, and the isotherms for different climate change projection time scale in Figures B-5 to B-7 in Appendix B.

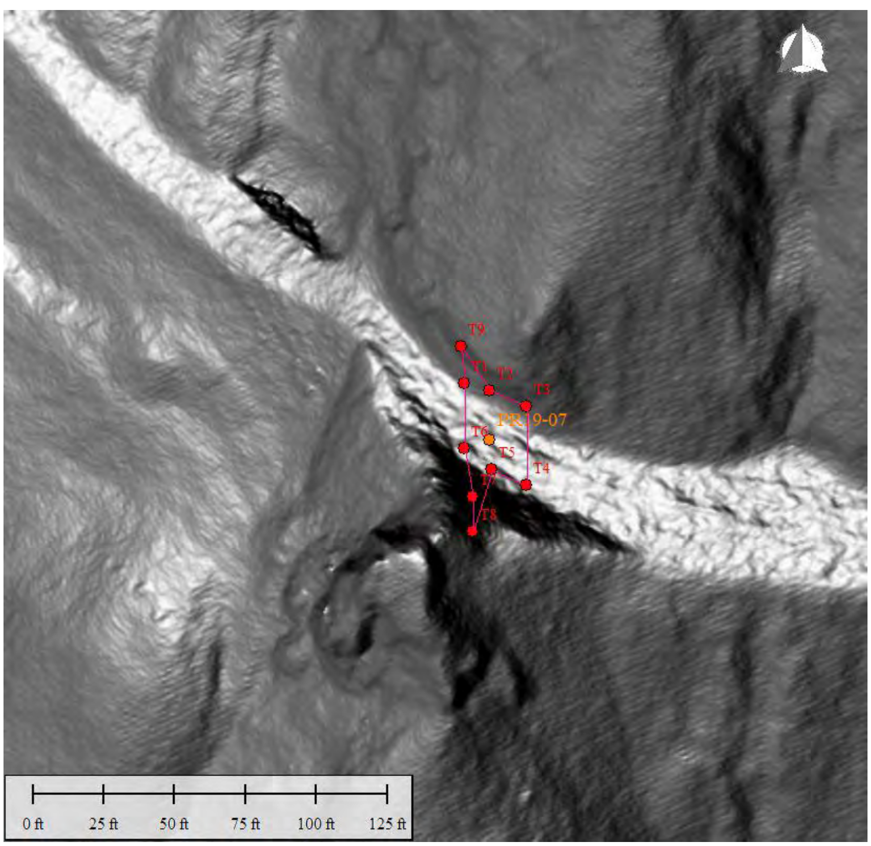
4.2. 3D Model Results – East Bridge Abutment

The effect of climate change on the temperature with depth at the east bridge abutment in reference to the available thermistor data (PR19-07) is shown in Figure 4-7. The recorded temperatures for 2019 and 2020 and the base case are shown for comparison. The recorded temperature and model results are near 32°F during calibration. The climate change analysis considered that the landslide has progressed and exposed a 50 ft vertical drop at the abutment location. The frozen ground (<32°F) in 2020 was encountered approximately 15 ft below the ground surface. By 2060, this increases to a depth of 35 ft, and by 2100, the unfrozen layer is projected to be at least 100 ft below the ground surface, indicating that degradation of the ice-rich permafrost underlying the East Bridge Abutment is likely.

Although there are uncertainties to the evolving nature of climate change models, these results generally follow a trend consistent with climate warming where increasing ground temperatures are observed with each successive climate change step. Loss of support from the degrading permafrost may cause instability at the bridge abutment over the long-term with increased potential for evacuation of material at the east abutment, specifically the soil-like rock that forms the Pretty Rocks Landslide deposit. This should be accounted for in the detailed foundation design, and additional measures should be considered to keep the ground temperatures below 32°F for as long as this is practical.

4.3. Addition of Cooling

Monitoring locations for temperature with depth, relative to the location of PR19-07, are shown in Schematic 4-1. These monitoring locations are labeled from T1 to T9 and are discussed as potential thermosyphon locations. The model temperatures for these locations near the abutment to a depth of 110 ft below ground surface are shown in Figure 4-8 for the month of January and Figure 4-9 for the month of July. Within elevations 3520 ft to 3570 ft, the ground temperature increased by approximately 4°F between historical climate conditions (31°F) and the 2100 climate projection. Boundary conditions were added to the 3D thermal model at T1 to T9 between elevations 3520 ft and 3570 ft, to explore the feasibility of cooling existing ice-rich permafrost in the east bridge abutment area.



Schematic 4-1. Approximate location of thermosyphons at the east bridge abutment relative to PR19-07 used in the thermal model.

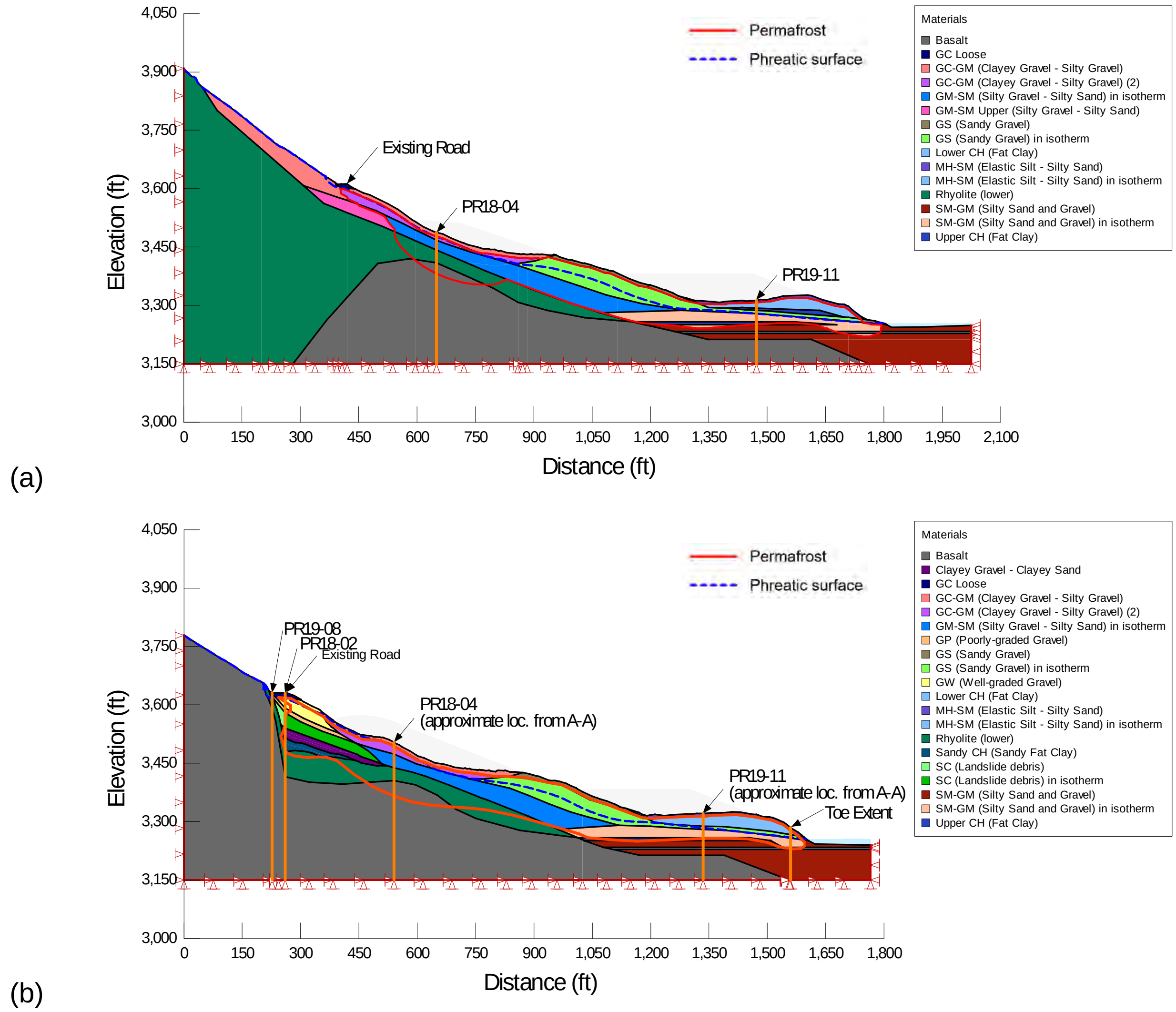
5.0 SPOIL DEFORMATION AND SLOPE STABILITY MODELING - METHODOLOGY

Deformation modeling was completed to understand the impact of spoil placement on the landslide area and how the change in stresses due to this placement may impact the landslide stability. The commercially available SIGMA/W, SEEP/W, and SLOPE/W programs in the GeoStudio 2021.4 software suite (SIGMA/W, Version 11.3.0.23668, SEEP/W Version 11.3.0.23668, SLOPE/W, Version 11.3.0.23668) were used to perform the analyses. Unlike the temperature models in Section 2.0 that are calibrated with temperature readings, deformation and stability modeling is governed by stress history, water flow, and the inherent strength of the soil and rock units. Without laboratory measurements or field data at several locations to better define the active landslide, the results presented herein only semi-quantitatively describe the impact of spoil placement based on the assumptions made in the analyses and should not be interpreted as the expected displacements once construction commences. The model was verified against current understanding of the landslide deformation from slope inclinometers, time-lapse photography, lidar and photogrammetry change detection, and local site understanding including typical behavior of rock glacier movements.

The presence of permafrost adds an additional layer of complexity and uncertainty, given that the software suite does not couple thermal, mechanical (stresses, deformation), and hydraulic (pore water pressure) conditions together implicitly or explicitly. The approach used in this report is to define the frozen and unfrozen zones from the thermal model and assign equivalent strength properties in SIGMA/W and SLOPE/W. Groundwater flow in SEEP/W is assumed to be occurring above the permafrost zone. The time component of the analysis is only used as a reference in the model and is not equivalent to real-time.

5.1. Model Cross-Section

The same model cross-sections from the Spoil TEMP/W models were used in the SIGMA/W and SLOPE/W models. The primary difference is that the materials assigned to the model were changed to have stress and hydraulic properties. In addition, the size of the permafrost at its warmest state, which is encountered around October of each year during the calibration period, was used as the template for assigning frozen and unfrozen properties. Cross-sections of Section A-A and Section C-C are shown in Schematic 5-1 with a delineation of where the permafrost is bounded (red line) and the phreatic surface (blue-dashed line). Schematic 5-1 documents the modeled existing stress state for these sections using the permafrost extent under historical climate conditions. As shown in Figure 4-4 to Figure 4-6, the permafrost area is predicted to decrease by 2099/2100 and this will impact the displacements and slope stability of the existing landslide over a long period as permafrost (frozen soil) has a higher shear strength. To determine the stability of the slope under the expected permafrost conditions from the 2100 climate projection (i.e. the long-term stability after spoil placement), the model cross-sections were revised with the 2100 climate step permafrost extents. It is recognized that these models represent two distinct time periods, thus cumulative displacements over the time periods between these two analyses (e.g., 2040, 2060, 2080) are not modeled. Without the explicit coupling mentioned earlier, the stress history (i.e., consolidation due to soil subjected to freezing and thawing with and without additional confining stresses) is not accurately captured over the long-term.



Schematic 5-1. Cross-sections for (a) Section A-A and (b) Section C-C used in the deformation and slope stability analyses.

5.2. Boundary Conditions in Deformation Modeling

The boundaries applied to Section A-A and Section C-C are shown in Schematic 5-1. Fixed x-displacement boundaries are applied on the rightmost and leftmost vertical boundaries, while a fixed x- and y-displacement boundary is applied along the base of the model. A hydraulic boundary was applied at several locations along the ground surface to mimic an assumed groundwater table that is at the surface upslope of the existing road and drops to 40 ft below ground surface at the toe of the landslide at PR19-11. An in-situ analysis and a steady-state seepage analysis were first completed to establish the initial stress and groundwater conditions within the cross-section.

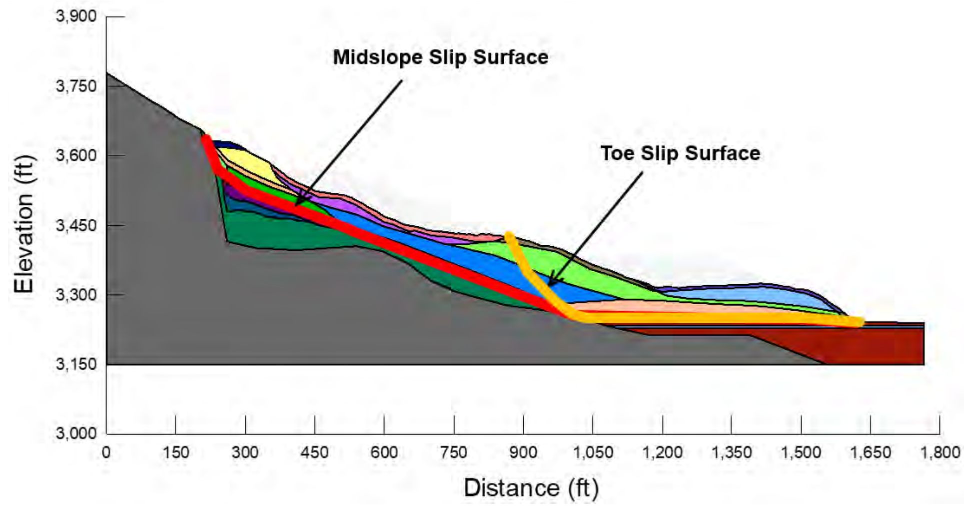
The initial stress condition obtained from the in-situ analysis does not distinguish the stresses in each element in the model if it is at a plastic state (yielding) or within the elastic state based on the material properties input in the program. The in-situ analysis only considers gravity activation of the stresses and can result in stresses outside the yield surface (illegal stress states) when the elastic material is replaced with an elastic-plastic material (GEOSLOPE International Ltd., 2021b). A stress redistribution step is added after the in-situ analysis to return stresses within a domain to legal stress space; that is, to a location in stress space that is on or below the yield surface (GEOSLOPE International Ltd., 2021b). After the stress redistribution step, a consolidation analysis was initiated with the displacements and strains zeroed at the beginning of the analysis (no spoil condition, NS). This ensures that the displacements obtained in subsequent steps are reflective of the spoil placement. The consolidation model couples SIGMA/W and SEEP/W to obtain a solution, where spoil placement can generate pore water pressures and additional displacements as the water drains. The hydraulic boundary conditions were removed at subsequent stages at the interface between the ground surface and the base of the spoil. The spoil placement scenarios and observation locations for Section C-C are shown in Figure 5-1.

5.3. Slope Stability Modeling

A stress-based stability analysis was conducted in SLOPE/W for the base case (no spoil condition, NS) and the spoil placement scenarios. The stress and pore water pressure conditions at the end of the consolidation analysis in SIGMA/W is used as the parent analysis in each SLOPE/W model. The rhyolite and basalt rock layers were considered as impenetrable materials and hence the slip surface cannot pass through these layers. A Mohr-Coulomb constitutive model is used in these analyses, where only the unit weight and shear strength (friction angle, cohesion) are needed. The cohesion is assumed to be zero for all materials. The block-search method with optimization was used to determine the slip surface and lowest factor of safety (FoS) at two locations: (a) midslope and (b) toe of the landslide.

The optimization option is an iterative procedure within the program that allows for adjustment of the shape of the failure surface. The critical slip surface from a regular search is always used as the starting slip surface in the optimization process (GEOSLOPE International Ltd., 2021a). The critical slip surface with optimization has a preference towards weak layers in the domain and further refinement of the shape can lead to a non-circular slip surface with a lower FoS. In most cases, a smaller FoS can be obtained after the optimization (GEOSLOPE International Ltd., 2021a). Without optimization, the slip surface reverts to the traditional slip surface (e.g. circular, planar, or composite).

The typical slip surfaces at these locations are shown in Schematic 5-2. As the spoil is added, it is expected that the minimum FoS will change, along with the corresponding slip surface. The slip surface obtained from the NS case is used as an additional check as to how the spoil placement may influence the stability and deformation process of the landslide prior to any changes. Similarly to the deformation models, the cross-section was modified to correspond to the frozen and unfrozen layer boundary from the temperature models at year 2100, as in Section 4.1.



Schematic 5-2. Typical slip surfaces at Section C-C prior to any spoil placement.

The FoS obtained in the slope stability analyses only considers the driving shear forces and the available shear resistance from the soil properties used in the model. The slope stability analyses do not consider the effect of cyclical freezing and thawing on shear strength, creep conditions, nor the consolidation of the active layer as the permafrost degrades over time. The change in model geometry due to settlements, ice segregation or frost heave, and any changes in shear strength as the bonding between ice and soil changes, will also influence the FoS, and are not reflected in these analyses.

5.4. Mechanical and Hydraulic Material Properties

The mechanical and hydraulic properties used in the analyses are summarized in Table 5-1. In the absence of laboratory and field measurements for each soil and rock unit, mechanical (effective stress conditions) and hydraulic properties available from other on-site testing and literature were used (Budhu, 2011), based on descriptive information at the relevant boreholes evaluated in the landslide area (PR18-02, PR18-04, PR19-08, PR19-11). Adjustments and modifications to some of the values presented in Table 5-1 were done to best represent the behavior of the landslide considering that the current FoS for the slope is at or near 1.0 based on its activity. Similar to the thermal models, the stratigraphy was approximated from borehole data given the information is sparse between the existing road and at the toe of the landslide. The frozen and unfrozen zones from the thermal models at the expected time of spoil placement (between mid-August and mid-October) was traced to delineate the change in mechanical and hydraulic properties for the same type of material.

Table 5-1. Summary of mechanical (effective conditions) and hydraulic properties in 2D deformation and slope stability models.

Material Name	Density (pcf)	E (psf)	ν	e	ϕ' (°)	k_x (ft/hr) *	VWC	m_v (/psf)	Model
Basalt	162.30	104,427,170	0.15	0.05	---	1.18e-07	0.236	4.79e-10	Linear Elastic
Rhyolite	152.93	83,541,737	0.25	0.05	---	1.18e-07	0.117	4.79e-10	Linear Elastic
Waste Material	127.34	522,135.86	0.30	0.27	---	11.81	0.186	4.79e-06	Linear Elastic
GC-SC	133.58	730,990.20	0.30	0.81	33	11.81	0.495	1.44e-06	Mohr-Coulomb
GC Loose	127.34	522,135.86	0.25	0.22	35	118.08	0.151	4.79e-06	Mohr-Coulomb
GC-GM	120.00	626,563.03	0.30	0.54	27	1.27	0.255	4.79e-06	Mohr-Coulomb
GC-GM (in isotherm)	120.00	563,906.73	0.30	0.54	27	1.27	0.255	4.79e-06	Mohr-Coulomb
GM-SM (in isotherm)	139.83	526,312.94	0.32	1.62	25	1.27	0.840	1.44e-06	Mohr-Coulomb
GP	127.34	522,135.86	0.20	0.33	31	118.08	0.218	1.44e-08	Mohr-Coulomb
GS	146.07	835,417.37	0.25	1.35	27	11.81	0.78	4.79e-07	Mohr-Coulomb
GS (in isotherm)	146.07	751,875.63	0.25	1.35	27	11.81	0.78	4.79e-07	Mohr-Coulomb
GW	127.34	522,135.86	0.30	0.27	34	118.08	0.186	1.44e-08	Mohr-Coulomb
Lower CH	133.58	417,708.69	0.30	0.81	10	1.18e-02	0.495	1.24e-05	Mohr-Coulomb
MH-SM	95.51	313,281.51	0.30	1.35	25	1.18e-02	0.510	6.22e-06	Mohr-Coulomb
MH-SM (in isotherm)	95.51	281,953.36	0.30	1.35	20	5.13e-03	0.510	9.58e-06	Mohr-Coulomb
Sandy CH	139.83	584,792.16	0.27	0.30	32	1.16e-03	0.204	6.22e-06	Mohr-Coulomb
SC Landslide Debris	89.26	313,281.51	0.33	0.49	29	1.18e-01	0.218	2.49e-06	Mohr-Coulomb
SC Landslide Debris (in isotherm)	125.00	281,953.36	0.20	0.50	25	6.86e-01	0.218	2.49e-06	Mohr-Coulomb
SM-GM	139.83	522,135.86	0.28	0.81	23	1.18	0.518	1.01e-06	Mohr-Coulomb
SM-GM (in isotherm)	139.83	469,922.27	0.28	0.81	25	3.27	0.518	6.22e-07	Mohr-Coulomb
Upper CH	101.75	313,281.51	0.40	1.62	10	1.18e-02	0.612	1.24e-05	Mohr-Coulomb

Notes: E – Elastic modulus, ν – Poisson's ratio, e – void ratio, ϕ' – effective friction angle
k_x – hydraulic conductivity in the x-direction, VWC – volumetric water content, m_v – modulus of volume compressibility
* A ratio of k_x/k_y is assumed to be equal to 1; that is, the hydraulic conductivity in the x-direction is the same as the y-direction.

6.0 DEFORMATION AND SLOPE STABILITY MODELING RESULTS

6.1. Deformation Results

The results of the deformation analysis are relative to the material properties selected and model limitations, and should not be considered as absolute values of expected ground displacements. The behavior of the rock glacier (Pretty Rocks Landslide) is complex and three-dimensional, and the numerical tool used in this report cannot fully encapsulate these displacements, in addition to the limited ground data available to us at the time of assessment and uncertainties related to climate projections. More sophisticated numerical tools such as FLAC (2D or 3D) and ABAQUS may allow for more explicit coupling between thermal, mechanical, and hydraulic components; however, these tools still require additional laboratory and field data to reasonably capture the evolution of displacements and source of groundwater flow whether any spoil is added or not on the landslide under changing climate conditions. And even then, significant uncertainties exist from available constitutive models.

6.1.1. At Time of Spoil Placement

The displacement contours for the different spoil placement scenarios are shown in Figure 6-1. Additional load due to spoil placement contributes to larger displacements at all observation locations (Upslope, Midslope, Toe). Based on the displacement contours in Figure 6-1, there are larger displacements developing outside these observation locations. A Toe Extent location was selected as an additional location to monitor these displacements. Placing the spoil in S1 will mostly mobilize displacements between the Upslope and Midslope locations. S1 and S1/S2 show displacements at the Toe Extent of the slide that are considerably less than the displacements if the spoil was all placed in S2. The figures also indicate that the existing road will continue to move in all spoil scenarios.

The x-displacements with depth at discrete locations along Section C-C at the time of spoil placement for the different scenarios are shown in Figure 6-2. The loading condition in Section A-A is less than Section C-C (see Schematic 2-2) with less spoil mound in the 2D cross-section and would therefore have less displacements. Analysis results for Section A-A are provided in Appendix B.

6.1.2. Climate Change

The cumulative displacements projected in the model by 2100 (Figure 6-3, Figure 6-4) are due to the change in material properties from frozen to unfrozen based on the isotherms shown in Figure 4-4, Figure 4-5, and Figure 4-6. Additional displacements developed at several locations along the landslides when comparing Figure 6-1 and Figure 6-3. In particular, the displacements at the Toe Extent location where the spoil ends for S1/S2 and S2 scenarios have increased by more than 5 ft, with S2 having larger displacement contours with a thicker spoil at the Toe location of the landslide. The isotherms indicate that no appreciable displacements developed between Figure 6-1 and Figure 6-3 for the S1/S2 scenario where part of the spoil is at concavity near the Midslope location. Based on these results, a combination of spoil placement between S1 and S2 limits the development of displacements at the Midslope, Toe, and Toe Extent locations under climate change projections where permafrost extents have decreased.

The x-displacements with depth at discrete locations at the end of the climate change analyses are shown in Figure 6-4 for different spoil scenarios. The results from the time of spoil placement (Figure 6-2) are added in Figure 6-4 for comparison. The cumulative displacements for S1 and S1/S2 were marginal in the Midslope and Toe locations, but significant displacements at the Upslope and Toe Extent were encountered for all spoil scenarios because of a thicker depth of thaw at these locations. Based on the two distinct time steps investigated (time of spoil placement, end of climate change analyses), the Upslope location will have the same order of displacements for all spoil scenarios, while a combination of spoil placement like S1/S2 will have the least displacements for the Midslope and Toe locations, and marginal increase at the Toe Extent location. These estimated displacements due to climate change are likely to be underestimated as they do not account for the seasonal freeze-thaw cycles and the consolidation occurring over that long period as the thawed water drains from the landslide area. For this reason, as well as other limitations discussed herein, the results are appropriate for comparison of alternatives, not for predicting long term movement of the Pretty Rocks Landslide.

6.2. Slope Stability Results

6.2.1. At Time of Spoil Placement

The landslide is currently active and model results showing the FoS values for the NS condition at or near 1.0 (Figure 6-5) provides additional confidence on the modeling procedure and parameters. In Figure 6-5, typical Midslope and Toe slip surface locations were observed from different model runs and are used in tracking several slope stability results. These Midslope and Toe slip surface locations are different from Midslope and Toe locations described in Section 5.0.

The slope stability results at the Midslope and Toe slip surfaces for the different spoil scenarios for Section C-C are shown in Figure 6-6 and tabulated in Table 6-1. The FoS values without optimization and using the original (NS) slip surface are also summarized in this table. Any spoil placement for the different scenarios will either increase or decrease the stability of the slope depending on the action of spoil load on mobilizing or stabilizing the current slip surface.

For S1 scenario, the Midslope slip surface has a 5% decrease in FoS, but with a 3% increase in FoS at the Toe slip surface. For S2 scenario, the Midslope slip surface has a 20% increase in FoS, but with a 12% decrease in FoS at the Toe slip surface. The placement of all spoil in either scenario will increase one slip surface but consequently decrease another. For S1/S2 scenario, which places the spoil load in S1 and S2 at reduced volumes, the Midslope and Toe slip surfaces have an increase of 5% and 7% in FoS, respectively.

Adding the spoil in either S1/S2 or S2 scenarios acts like a toe berm for the Midslope slip surface and hence the relative increase in its FoS values as more spoil is added. Placing all of the spoil in the S2 scenario adds significant driving forces at the Toe slip surface which consequently decreases the FoS. This reduction in FoS is consistent with the model displacements recorded at the Toe Extent in Figure 6-2. The slip surfaces in Figure 6-6 demonstrate that S1/S2 scenario will not materially alter the current state of the landslide, whereas the other scenarios might. Slip surfaces for the different spoil scenarios for Section A-A are provided in Appendix B.

Table 6-1. FoS results at Section C-C for different spoil placement scenarios.

Scenario	Midslope FoS		Toe FoS		Midslope FoS using NS slip surface*	Toe FoS using NS slip surface*
	w/ Opt.	w/o Opt.	w/ Opt.	w/o Opt.	w/ Opt.	w/ Opt.
NS	1.01	1.06	1.10	1.66	n/a	n/a
S1	0.96	1.12	1.13	1.54	0.98	1.19
S1/S2	1.06	1.23	1.18	1.41	1.06	1.24
S2	1.22	1.27	0.97	1.16	1.09	1.25

Note: * The slip surface for scenarios S1, S2, S1/S2 is forced to follow the NS scenario slip surface.

6.2.2. Under Climate Change Conditions

The slope stability results at the Midslope and Toe locations for the different spoil scenarios for Section C-C using the revised isotherms at year 2100 (see October 2099 of Figures 4-4 to 4-6) are shown in Figure 6-7 and the FoS results are tabulated in Table 6-2. As described in Section 6.1.2, mechanical properties in the deformation models were updated based on the permafrost conditions from the 2100 climate projection thermal analysis. The change in material properties and reduction in size of the permafrost extent alter the stress conditions in the model domain. These updated stress conditions are then used as the initial condition of the stability model for 2100 climate projection.

Table 6-2. FoS results at Section C-C for different spoil placement scenarios at YR 2100.

Case	Midslope FoS		Toe FoS		Midslope FoS using NS slip surface	Toe FoS using NS slip surface
	w/ Opt.	w/o Opt.	w/ Opt.	w/o Opt.	w/ Opt.	w/ Opt.
S1	0.98	1.16	1.14	1.54	1.02	1.19
S1/S2	1.19	1.27	1.22	1.42	1.10	1.25
S2	1.22	1.27	0.99	1.17	1.10	1.27

Note: The NS Scenario was not modeled for 2100.

The stability results under climate change conditions indicate that no appreciable changes in FoS values will occur for an already active landslide. Marginal increase in FoS values between 2% and 4% for results with optimization were observed for all conditions, except for S1/S2 at Midslope which increased by about 12%. The spoil added at the Toe location acts as stabilizing for the Midslope slip surface. However, the slope stability model does not predict any local failures in the long-term over the continuous freeze-thaw cycles nor the change in shear strength of the soil layers due to consolidation over time. Therefore, these observations are only valid under the assumptions made. Slip surfaces for the different spoil scenarios under climate change conditions for Section A-A are provided in Appendix B.

7.0 DISCUSSION AND RECOMMENDATIONS

7.1. Spoil Disposal Area

There is a desire to place spoil from project earthwork on the Pretty Rocks Landslide to avoid the impacts and costs of hauling it offsite. The anticipated in-situ rock cut volume to be generated is approximately 3.0 million cubic ft (111,165 cubic yards) with bulking from material excavation, transport and placement to result in a larger placed spoil volume. Three scenarios for spoil placement were evaluated to bracket the range of alternatives that might be preferred.

The Pretty Rocks Landslide, which is a rock glacier, is an active slide exhibiting steady creep behavior, typical for rock glaciers. A slope stability analysis using a Mohr-Coulomb constitutive model showed a factor of safety (FoS) at, or near 1.0 for current conditions, i.e., without the additional loading due to placement of the spoil. This is the base case against which alternatives for spoil placement were evaluated. Scenario S1/S2 for spoil placement was the scenario which did not result in significant decreases to the FoS of the modeled slip surfaces. This scenario has placement of some spoil higher on the landslide, and some placed lower on the landslide, and setback from the toe slope. Thus, based on the limit equilibrium slope stability model, it is the preferred scenario.

Deformation analysis was also performed for three scenarios of spoil placement. These analyses provide a measure of impacts of spoil placement because they model deformations. However, given the uncertainties in material properties, geometry, the mechanics of slide movement, and the expected changes in climate, and landslide response, the measures of movement are only valuable for comparing alternatives, including, in a relative sense, the alternative where no spoil is placed on the landslide. They should not be used to compare with future deformations of Pretty Rocks Landslide nor be used for other purposes.

The maximum deformations associated with the S1/S2 scenario are less than the S1 or S2 scenarios in the extent of the landslide that is appreciably deformed by spoil placement (Figure 6-3) or magnitude, when considering a combination of the three observation points below the road (Figure 6-2). At increasing distance below the road, the S1/S2 model deformations are approximately 0.7, 1.0 and 6.0 ft in the horizontal direction, whereas the S1 deformations are 5.3, 4.1 and 3.6 ft, and the S2 deformations are 1.4, 3.5 and 13.7 ft. Given the modeled climate conditions for year 2100, the deformation at these observation points all increase, but the increase is least for the S1/S2 Scenario, where the impact of climate causes approximately a 50% increase in modeled deformation, to 9 ft near the toe (Figure 6-4). If no spoil is placed, the deformation is modeled to be near 1 ft for 2100 projected conditions.

The deformation under the modeled current permafrost extents, and the deformation under the 2100 projected permafrost extents, represent “snap-shots” of time. The 2100 projection results are not cumulative of deformation that happens prior, and the absolute values of deformation from all the modeling reported here are useful only for comparisons, for reasons discussed previously. One qualitative comparison made is with respect to current deformation at the locations modeled. Current deformation is assessed by looking at lidar- and photogrammetry-based change detection, as available through Cambio™ or other means for this site. Using the iterative closest point change detection method in Cambio™, the average annual change is approximately 1 to 1.5 ft from 2015 to 2021 at the location where the modeling results show 6 ft (current conditions) or 9 ft (2100 projection) of horizontal movement. In a qualitative sense, these deformations are judged to be similar.

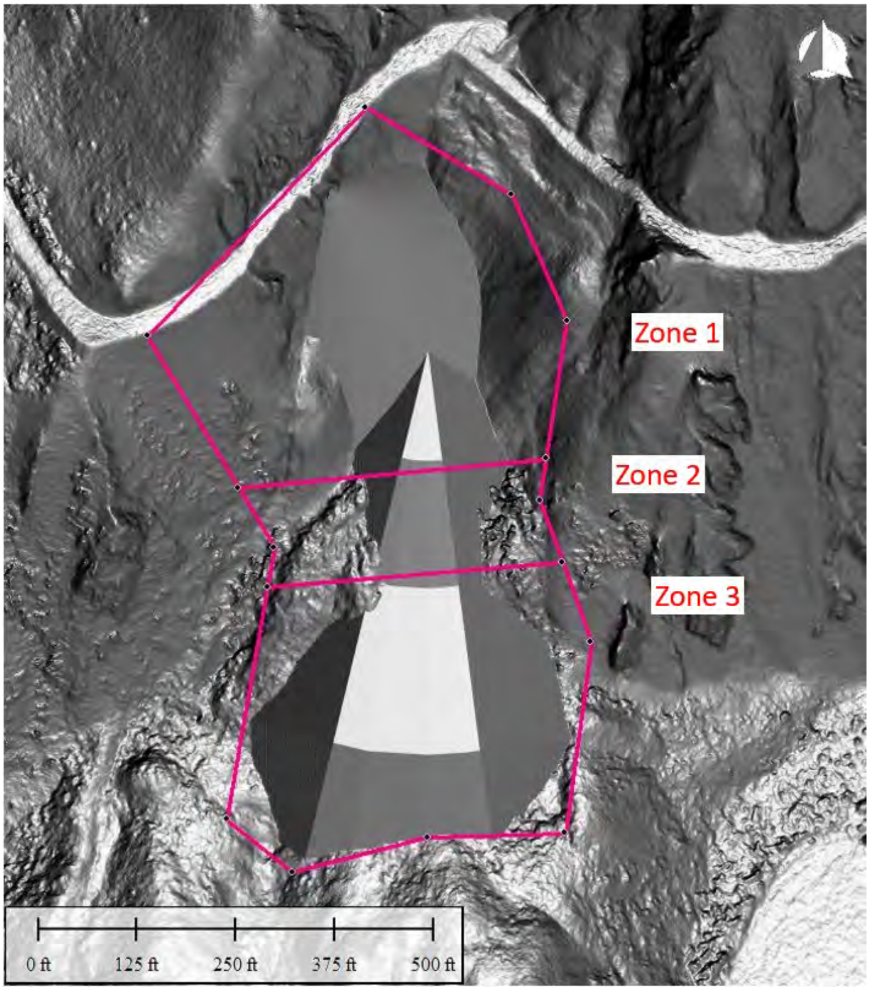
Thus, the stability analysis and current climate deformation modeling leads to the opinion that a spoil placement scenario similar to S1/S2 is unlikely to materially impact stability and deformation under current conditions. The deformation modeling for 2100 conditions lead to the opinion that greater deformations can be expected under projected future climatic conditions than current ones. Furthermore, placing of spoil, even in the modeled S1/S2 scenario, which is least impactful, leads to greater modeled deformation than not placing spoil on the landslide. When these findings of relative movement are compared with the rate of movement observed over the period of 2015 to 2021, BGC concludes that spoil placement in a scenario similar to that modeled as S1/S2 will not materially alter the deformation characteristics of the Pretty Rocks Landslide.

In consideration of these findings, the recommended spoil configuration is shown in Schematic 7-1, with the maximum depths summarized in Table 7-1, is a conceptual geometry used to confirm spoil placement volumes consistent with the recommendations for spoil placement outlined below. This conceptual geometry has a volume of approximately 150% of the preliminary rock cut volume.

Table 7-1. Recommended spoil area footprint zones on Pretty Rocks Landslide.

Zone	Point #	Latitude	Longitude	Max Fill Depth (ft)
Zone 1	Z1-1	63° 32' 09.157" N	149° 49' 10.950" W	35
	Z1-2	63° 32' 11.989" N	149° 49' 04.855" W	
	Z1-3	63° 32' 10.900" N	149° 49' 00.788" W	
	Z1-4	63° 32' 09.333" N	149° 48' 59.265" W	
	Z1-5	63° 32' 07.620" N	149° 48' 59.850" W	
	Z1-6	63° 32' 07.270" N	149° 49' 08.434" W	
Zone 2	Z2-1	63° 32' 07.270" N	149° 49' 08.434" W	20
	Z2-2	63° 32' 07.620" N	149° 48' 59.850" W	
	Z2-3	63° 32' 07.102" N	149° 49' 00.027" W	
	Z2-4	63° 32' 06.332" N	149° 48' 59.408" W	
	Z2-5	63° 32' 06.032" N	149° 49' 07.639" W	
	Z2-6	63° 32' 06.526" N	149° 49' 07.442" W	
Zone 3	Z3-1	63° 32' 06.032" N	149° 49' 07.639" W	60
	Z3-2	63° 32' 06.332" N	149° 48' 59.408" W	
	Z3-3	63° 32' 05.335" N	149° 48' 58.606" W	
	Z3-4	63° 32' 02.970" N	149° 48' 59.356" W	
	Z3-5	63° 32' 02.923" N	149° 49' 03.200" W	
	Z3-6	63° 32' 02.491" N	149° 49' 06.970" W	
	Z3-7	63° 32' 03.152" N	149° 49' 08.792" W	

Note: See schematic 7-1 for zone locations.



Schematic 7-1. Recommended spoil area delineation and conceptual spoil placement geometry for volumetric calculations.

Based on the information available today and the stability assessments presented in this report, BGC recommends the following regarding the spoil disposal area:

- Prior to project completion, all spoil material should be placed on the Pretty Rocks Landslide within the footprint documented in the table of coordinates provided in Table 7-1.
- Spoil placed for temporary access on the existing road alignment or for other construction reasons should be graded to meet other project requirements and this spoil placement plan prior to project completion.
- Final spoil configuration should have more of the spoil volume within Zone 3 than Zone 1.
- The slopes of the spoil material should not exceed 2H:1V.
- The final spoil configuration should be graded to drain and meet the project criteria for aesthetics.

BGC understands the Design-Built Contractor may utilize spoil material during construction to maintain access across the landslide and the design may be altered from the preliminary geometry used in these analyses. Thus, the quantities of material assumed in the model may not be consistent with the final amount of spoil placed upon construction completion.

It is important to note that landslide acceleration may not occur immediately (i.e., at the time of spoil placement) but can still be linked to the location of spoil placement in the future. The numerical models indicate that the placement of the spoil on the landslide is not expected to result in a sudden instability. However, it cannot be ruled out that, independent on any spoil placement, a sudden failure occurs in the future as the ground thermal regime, stresses, and pore water pressure conditions change and new equilibriums are established.

7.1.1. Spoil Placement and Landslide Deformation Monitoring

As indicated, multiple assumptions and simplifications had to be made for assessing how the dynamics of the landslide may be impacted in response to the spoil placement. To identify unanticipated changes in its dynamics, BGC recommends the following to monitor the spoil placement and landslide deformation during construction. Such monitoring will allow documentation of the landslide deformation and allow responsive alterations to spoil placement activities should unexpected landslide behavior be observed. This construction monitoring could be adapted into a long-term performance monitoring post-construction. Spoil placement and landslide deformation monitoring is exclusive of any other monitoring for safety or any other project needs.

- Topographical changes and potential impact to the landslide should be monitored:
    - Baseline topographical surveys should be made within two weeks of initial project earthwork, including grading of temporary access or other site preparation.
    - Repeat topographical surveys should be made no less frequent than every two weeks during construction activities, and within two weeks of first access to the site in the spring of each construction season, regardless of whether earthwork is ongoing or planned.
    - Topographical data collection should have a lateral extent sufficient to capture movement within the Pretty Rocks Landslide, the slope west of the east abutment, and the slope below the western approach road, from Station 0+00 (the beginning) of the project.
    - The accuracy of data being collected must support topographic change detection analyses capable of assessing deformation within +/- 0.5 ft.
    - The Design-Built contractor should be required to present change detection drawings for remotely sensed data showing change vs. the previous dataset and vs. the baseline dataset to be provided within one week following data collection. Additionally, these topographical data should be provided digitally.
- Prism-based or Global Navigation Satellite System (GNSS)-based monitoring should be employed at a minimum of 10 key locations on the landslide or surrounding slopes. For initial planning, the coordinates of the spoil placement polygon corners or along the spoil

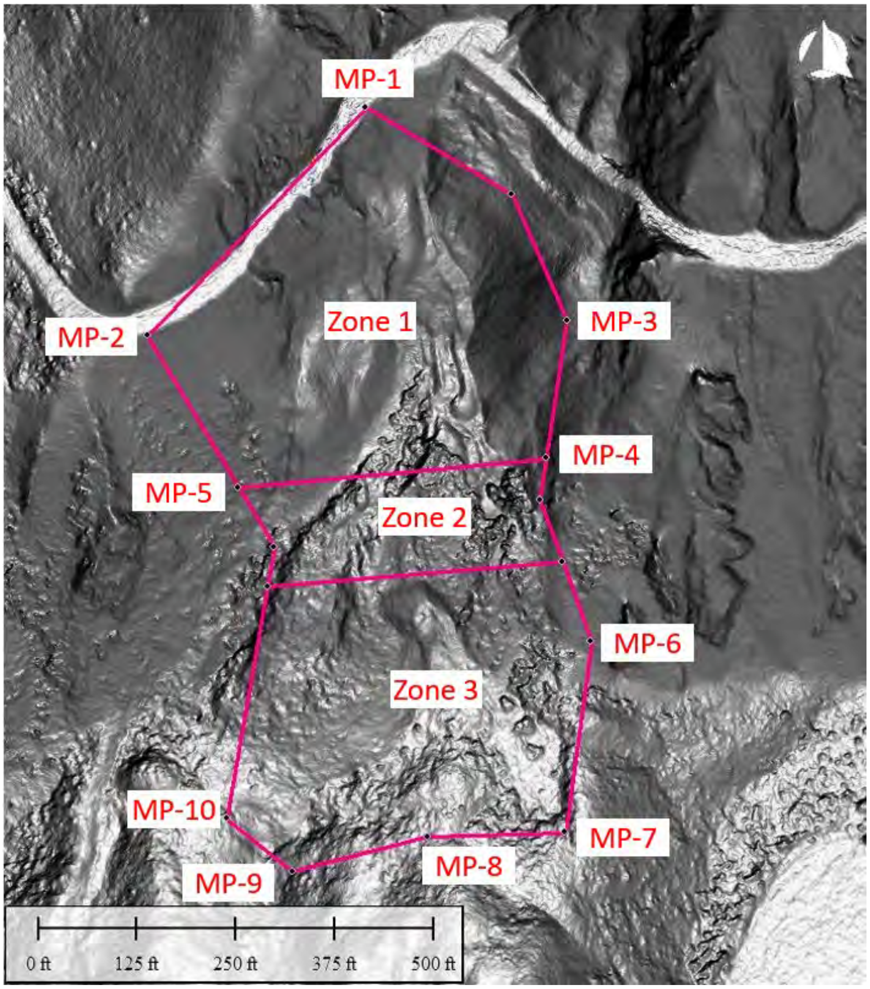
placement polygon have been assumed. They are as identified in Table 7-2 and shown in Schematic 7-2.

- These locations should be selected to complement topographical measurements and should be used in the areas captured by remote sensing and in any areas not visible (if any) through the remote sensing monitoring plan. The specific siting of these instruments should be such that they can be maintained throughout construction, and they should be promptly replaced if they are damaged or destroyed.
- Prisms /GNSS points, if applicable, should be installed on monuments that are fixed in the ground. Monuments should consist of a steel section, cement-grouted into a minimum 4-inch diameter borehole with an embedment of at least 5 ft. The steel section should be coupled to a riser section for prism attachment, if applicable. If greater than 3 ft in height, the verticality of the riser section should be measured in addition to location.
- Monuments should be monitored weekly during any earthwork construction and every two weeks, consistent with other monitoring at other times.
- Locations should be surveyed with a precision of less than 0.4"H / 0.6"V.
- The Design-Built contractor should create 3D displacement plots vs. time for all prisms / GNSS locations, if applicable.

- The Design-Built contractor should prepare and submit for approval an initial Trigger Action Response Plan (TARP) within one week after the baseline measurements and two subsequent surveys have been conducted. The TARP should have two successive alert thresholds for (a) additional monitoring and (b) revised construction activities and additional monitoring, and thresholds should exist for absolute measurements of change between successive surveys, for accelerations (rates of change), and plans for altering spoil placement schedule, if applicable.

Table 7-2. Location of monitoring pins in spoil area.

Point #	Latitude	Longitude	Location Description
MP-1	63° 32' 11.989" N	149° 49' 04.855" W	Uppermost point of Zone 1
MP-2	63° 32' 09.157" N	149° 49' 10.950" W	Point downslope of the east abutment
MP-3	63° 32' 09.333" N	149° 48' 59.265" W	Upper point on the east side of Zone 2
MP-4	63° 32' 07.620" N	149° 48' 59.850" W	Upper point on the west side of Zone 2
MP-5	63° 32' 07.270" N	149° 49' 08.434" W	Lower point of Zone 3
MP-6	63° 32' 05.335" N	149° 48' 58.606" W	Lower point of Zone 3
MP-7	63° 32' 02.970" N	149° 48' 59.356" W	Lower point of Zone 3
MP-8	63° 32' 02.923" N	149° 49' 03.200" W	Lower point of Zone 3
MP-9	63° 32' 02.491" N	149° 49' 06.970" W	Lower point of Zone 3
MP-10	63° 32' 03.152" N	149° 49' 08.792" W	Lower point of Zone 3



Schematic 7-2. Recommended spoil area delineation and initial location of monitoring pins.

For long-term monitoring of the spoil area and the landslide, a topographical survey of the landslide area should be generated annually, encompassing the entire construction footprint, following construction. Change detection should be completed to determine landslide deformation and changes to the status of the entire site. Surface deformation monitoring should be complemented by ground temperature and pore water pressure monitoring, if possible, to provide insight in changes of the ground thermal regime, permafrost degradation, and sub-permafrost ground water conditions, and give earlier indication of change prior to topographic change.

7.2. East Bridge Abutment

Ground temperatures measured at PR19-07 show a constant temperature of approximately 32°F with depth, indicative of the so called “zero-curtain effect.” The zero-curtain effect is observed when frozen material maintains a constant temperature near the freezing point as it absorbs latent heat during phase transition. Thus, the ground temperature data from PR19-07 indicate that permafrost is most likely in a state of degradation under current climatic conditions. Additionally, thermal modeling indicates that the ground temperatures at PR19-07 and its surrounding area, will most likely increase under climate change. The model shows permafrost degradation to a depth of at least a 100 ft below ground surface under the 2080 climate projection.

The stratigraphy of the East Bridge Abutment, presented in Section 2.2.2, consists of rhyolite rock of mixed weathering, fracture frequency, and strength grade overlying soil-like, hydro-thermically altered rhyolite clay. The clay is consistent with the material that forms the deposit of the Pretty Rocks Landslide. At the East Bridge Abutment, ice-rich permafrost is present within the clay material. Thus, permafrost degradation in the clay underlying the rhyolite has the potential to move with continued activity and retrogression of the landslide, possibly oversteepening the east bridge abutment. This degradation, as well as melting of ice in the rhyolite could also cause settlement of the abutment, even impacting deep foundations.

To mitigate this risk, cooling the abutment is recommended so the ice-rich clay remains frozen. The prism of material recommended for cooling is shown in Schematic 7-23. Current and historical records of the Pretty Rocks Landslide show a scarp at the East Bridge Abutment is present northwest of the planned abutment location (BGC, 2022, February 25). Upon completion of construction activities, it is likely this scarp will remain or possibly retrogress. This prism has been located, based on current project plans, to cool in clay material underlying the rhyolite at the East Bridge Abutment. The trapezoidal shape provides additional cooling on the face of the scarp.

Thermosyphons are convective devices which extract heat from the ground and discharge it to the atmosphere without the use of external energy (Long and Zarling, 2004; CSA, 2021); however, the heat extraction is only active during the winter months when the air temperatures at the condenser are lower than the ground temperatures of the evaporator section. A thermosyphon option has been evaluated in the thermal modeling. Other options such as active heat removal using generators and refrigeration, or wintertime forced air convection to cool the ground were excluded as options since they require on-site power and/or personnel to be available on site. Other passive cooling options, such as Air Convection Embankments (ACE) were excluded as they would not provide sufficient heat extraction at the depths required.

Cooling the foundation with thermosyphons at the east bridge abutment is aimed to ensure the ground will remain frozen (i.e., pore water is in a solid state) for the service life of the foundation and under climate change projections. A target ground temperature of 28°F is recommended for ground cooling. This temperature provides a buffer from the freezing point and improves the stability of the east bridge abutment. The frozen percentage of the pore water increases exponentially between values between 28 and 32°F (Andersland and Ladanyi, 2004). This improves stability by increasing the ice bonding of the clay. Currently, ground temperatures between 60 ft and 110 ft below the ground surface (elevation 3570 ft and 3520 ft) are between 30 and 31°F.

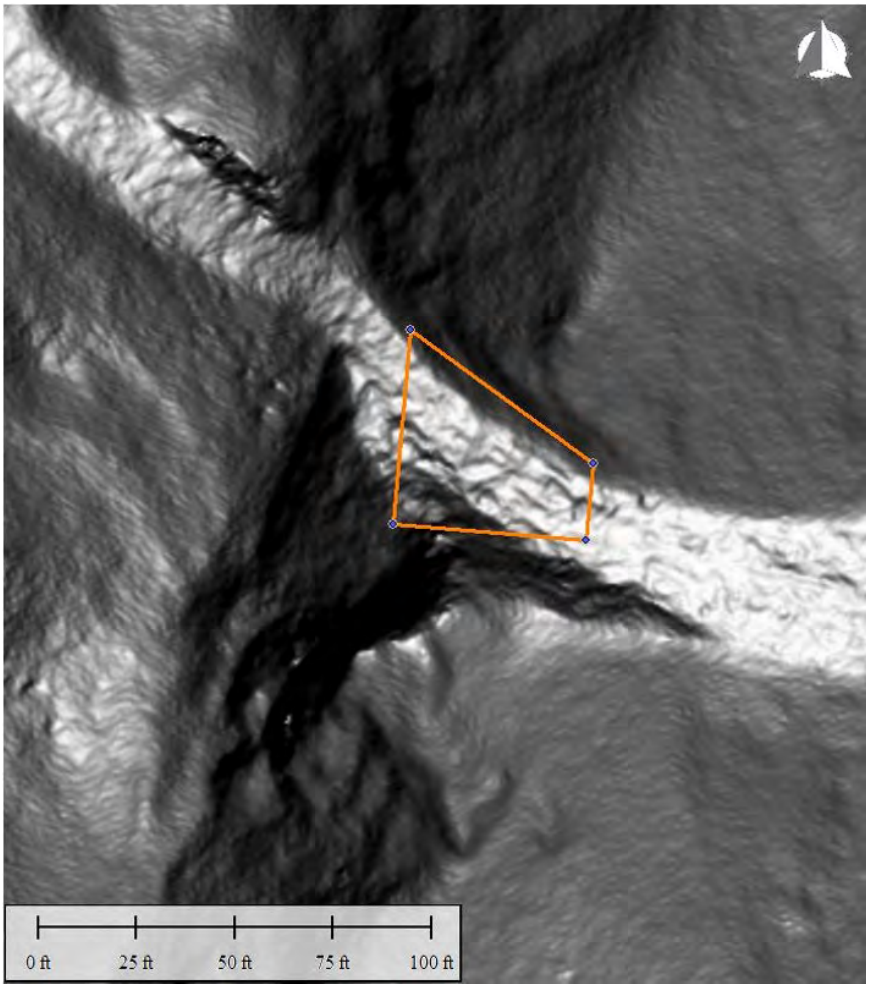
The effectiveness of thermosyphons is dependent on the depth of the zone of interest, the condenser section area, wind speed and air temperatures during the winter months when the thermosyphon is removing heat from the subsurface. The reduction in ground temperature to 28°F from the thermosyphon for the East Bridge Abutment Area may take several seasons. Trends for climate warming (Figure 2-1) show increased or consistent winter temperatures, but over a shorter winter season, and increasing summer temperature. As climate warming progresses, the summer heat inputs from the conductive and radiative heat transfer into the subsurface may not be balanced by the heat extraction from the thermosyphons and the winter conductive heat transfer. Thus, at some point in the future, a decision must be made based on the performance monitoring on whether maintaining the permafrost underlying the east abutment continues to be feasible. Increasing the surface area of the thermosyphon condenser may provide the additional heat extraction needed to keep the ground at 28°F in the future. However, considering current uncertainties in long-term climate projects and downscaling, specifically regarding wind speed, it is difficult to currently assess their long-term performance in detail.

Based on BGC's current understanding of the long-term thermal behavior of the east bridge abutment, BGC recommends the following:

- Thermosyphon evaporators should be installed at the east abutment within the footprint documented in the table of coordinates provided in Table 7-3 and shown in Schematic 7-3.
- Thermosyphons should be designed to maintain 28°F ground temperatures between elevation 3570 ft and 3520 ft in footprint defined by the points in Table 7-3.
- The thermosyphons should be designed using CMIP5 RCP8.5 projections for 2060 to 2080, as the climate input.
- The Design-Built contractor should be required to submit a deliverable for approval which documents the geothermal analyses that shows the design meets the criteria listed herein, as well as indicating the time to meet the 28°F ground temperature criteria.
- Thermosyphons condensers should be co-located on the south side of the alignment.
- Thermosyphons should be designed such that increasing the surface area of the thermosyphon condenser is possible.

Table 7-3. 28°F area in which thermosyphon evaporators should be installed at east abutment.

Point #	Latitude	Longitude
T-1	63° 32' 10.854" N	149° 48' 56.903" W
T-2	63° 32' 10.372" N	149° 48' 57.001" W
T-3	63° 32' 10.328" N	149° 48' 55.919" W
T-4	63° 32' 10.521" N	149° 48' 55.880" W



Schematic 7-3. Location of prism for maintenance of 28°F temperature, at least between elevations 3570 ft and 3520 ft at east bridge abutment area.

7.2.1. East Bridge Abutment Area Monitoring

As described in Section 7.2, the effectiveness of the thermosyphons is dependent on the depth of the zone of interest, the condenser section area, wind speed and air temperatures during the winter months when the thermosyphon is removing heat from the subsurface. BGC recommends the following be installed during construction to monitor the performance of these thermosyphons and ground temperatures at the East Bridge Abutment for the initiation during construction and as performance monitoring in the long-term:

- Four (4) thermistor strings should be installed for performance monitoring at depths between 2 and 120 ft below ground surface; locations should be determined from the results of the geo-thermal modeling with approval from WFLHD.
- Thermistor strings should have a minimum of 16 sensors, of which one sensor should be at 2 ft below ground surface, and one at 5 ft below ground surface, followed by the remaining sensors distributed at a sensor spacing of no more than 10 ft along the remaining length of the thermistor string.

- All thermistor strings used for monitoring should be zero-calibrated (calibration at 32°F (0°C)), have an accuracy of no more than ±0.1°C and a range of not less than +80°F to -90°F.
- Thermistor data loggers should be co-located with the thermosyphon condenser sections and protected from weather.
- An air temperature sensor should be co-located with the data loggers to measure ambient temperatures. This sensor should have the same accuracy and temperature range as the thermistor sensors and be protected from solar radiation and wind.
- Wind speed and direction sensors should be co-located with the data loggers to measure average wind speed and direction.
- All sensors (thermistor strings, air temperature, wind speed and wind direction) should be connected to data loggers to record every 4 hours readings and have sufficient memory to store data for at least 2 years.

Additionally, BGC recommends periodic monitoring of thermosyphon performance through the life of the structure via wintertime thermal imaging. An annual frequency should be used initially, and if changes are being observed in the future. Otherwise, a frequency of 2 to 5 years is recommended.

7.3. Continued Analysis

Numerical models are always simplifications and cannot fully capture all the underlying complexity of real-world conditions, specifically about future ones. Therefore, they should be updated as new information becomes available to re-calibrate the model base case and subsequent performance projections. The numerical models presented in this report are based on the available information from thermistor readings from 2020. Additional data from vibrating wire piezometers and thermistors recorded during 2021 and to-date in 2022 are expected to be available in April 2022. These data will provide complementary information that may be used for model calibration and to confirm the accuracy of the 2D and 3D temperature models developed herein. Updating the numerical models to the latest available information may reduce model uncertainties and provide more confidence in the future trends presented. BGC expects to issue an addendum to this report in May 2022 analyzing these new data, confirming the applicability of the current modeling in light of the new data, and documenting any changes to the modeling, if necessary.

8.0 CLOSURE

We trust the above satisfies your requirements at this time. Should you have any questions or comments, please do not hesitate to contact us.

Yours sincerely,

BGC ENGINEERING USA INC.
per:

Heather Brooks, Ph.D., PE
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AK AELC License No: 13138

Earl De Guzman, Ph.D., P.Eng.
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HMB/LUA/SAA/st

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FIGURES

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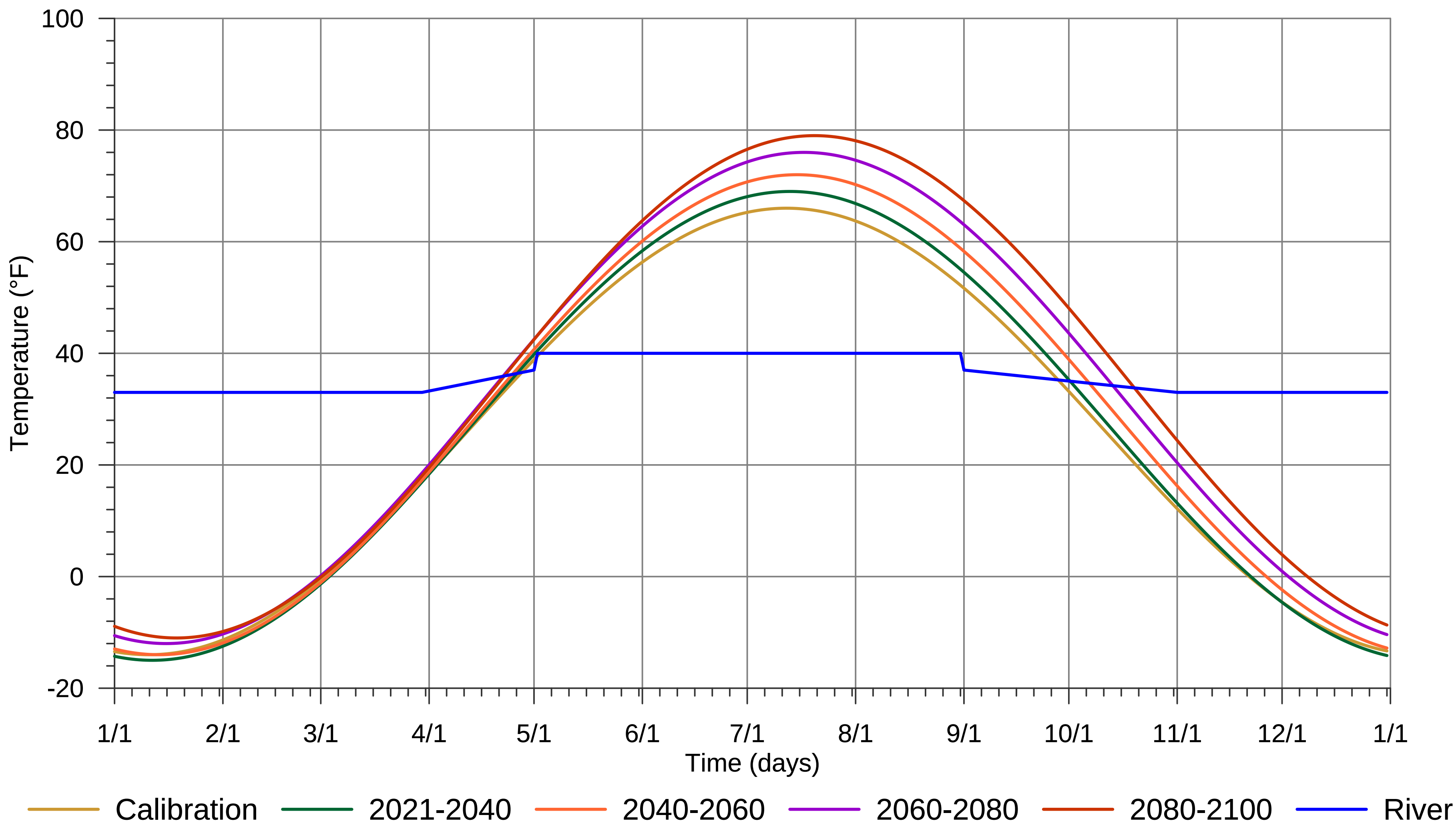

NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
2. SINUSOIDAL FUNCTION FOR CLIMATE CHANGE CONDITIONS WERE BASED ON RCP8.5 MODEL FROM CMIP5. SINUSOIDAL FUNCTIONS WERE FITTED THROUGH CLIMATE CHANGE PROJECTION TIME SCALES EVERY 20 YEARS (2020-2040, 2040-2060, 2060-2080, 2080-2100).
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PREPARED BY:	FIGURE TITLE:		
EDG	AIR AND RIVER TEMPERATURE BOUNDARY CONDITIONS		
CHECKED BY:	CLIENT:		
HMB	WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY:	SCALE:	PROJECT NO:	FIGURE NO:
LUA	NTS	2000004	2-1

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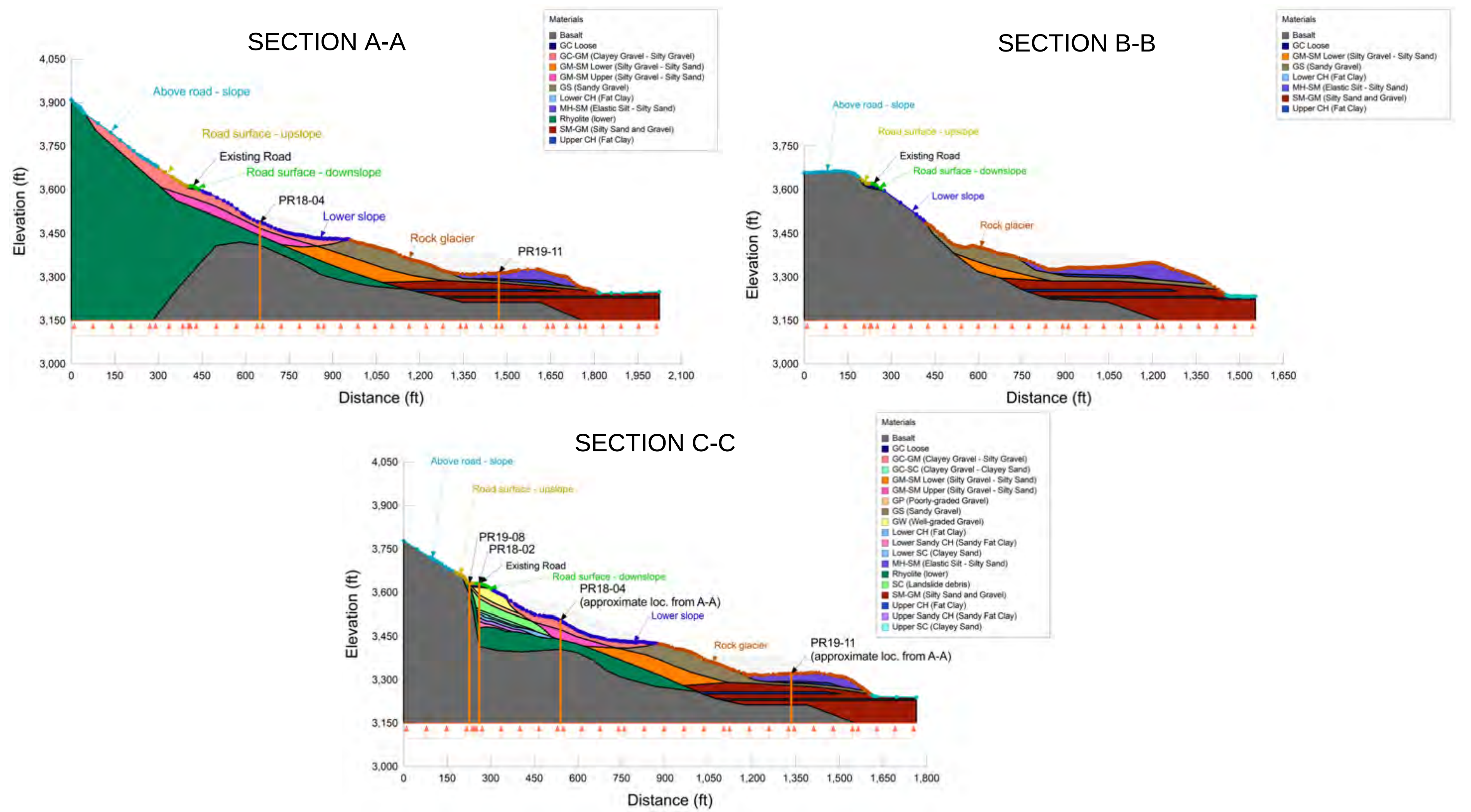

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2. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

PREPARED BY: EDG	FIGURE TITLE: n-FACTOR LOCATIONS APPLIED IN TEMP/W		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: 2-2

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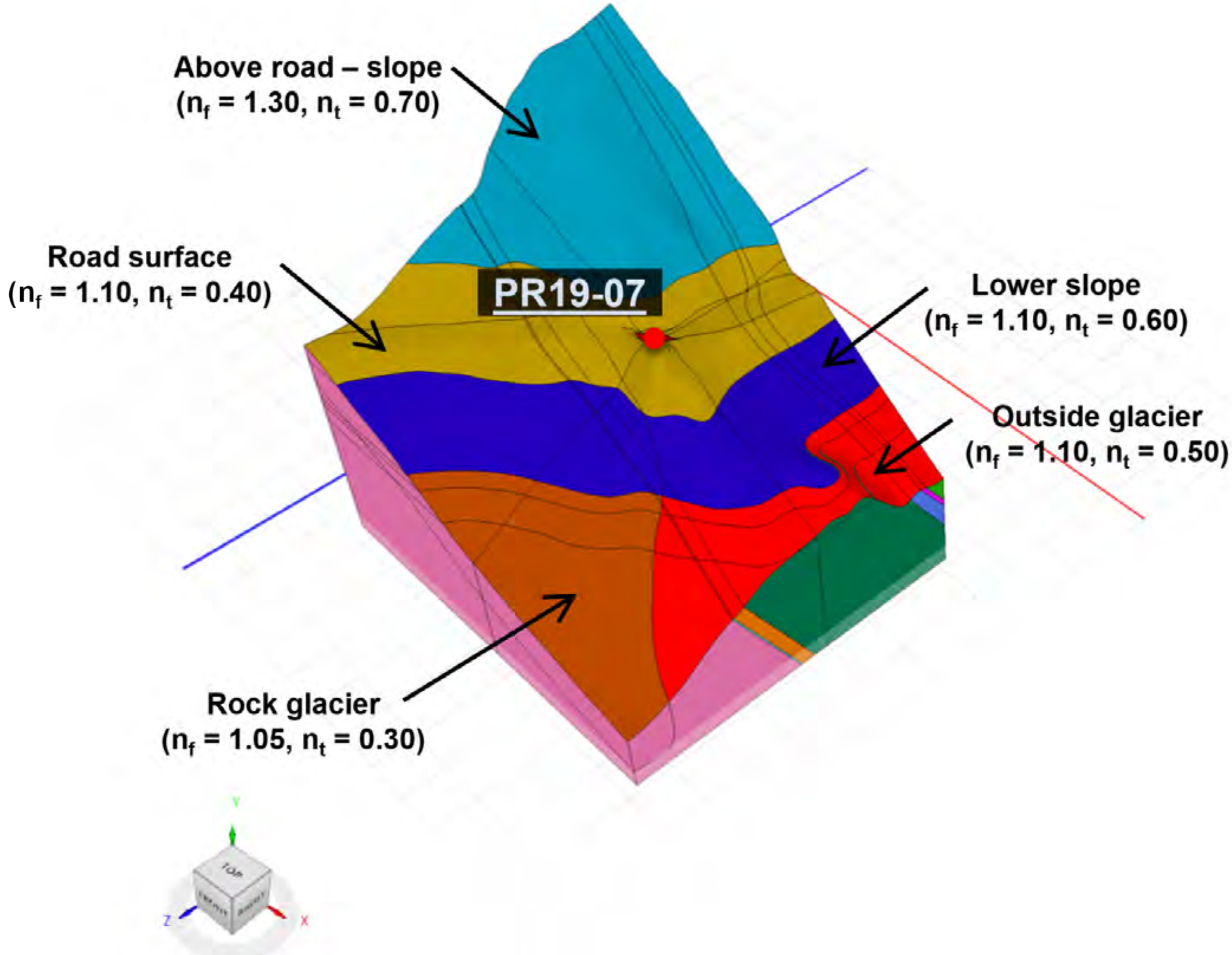

NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
2. SQUARE GRIDS ARE 50 FT.
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PREPARED BY:	FIGURE TITLE:		
EDG	n-FACTOR LOCATIONS APPLIED IN TEMP3D		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: 2-3

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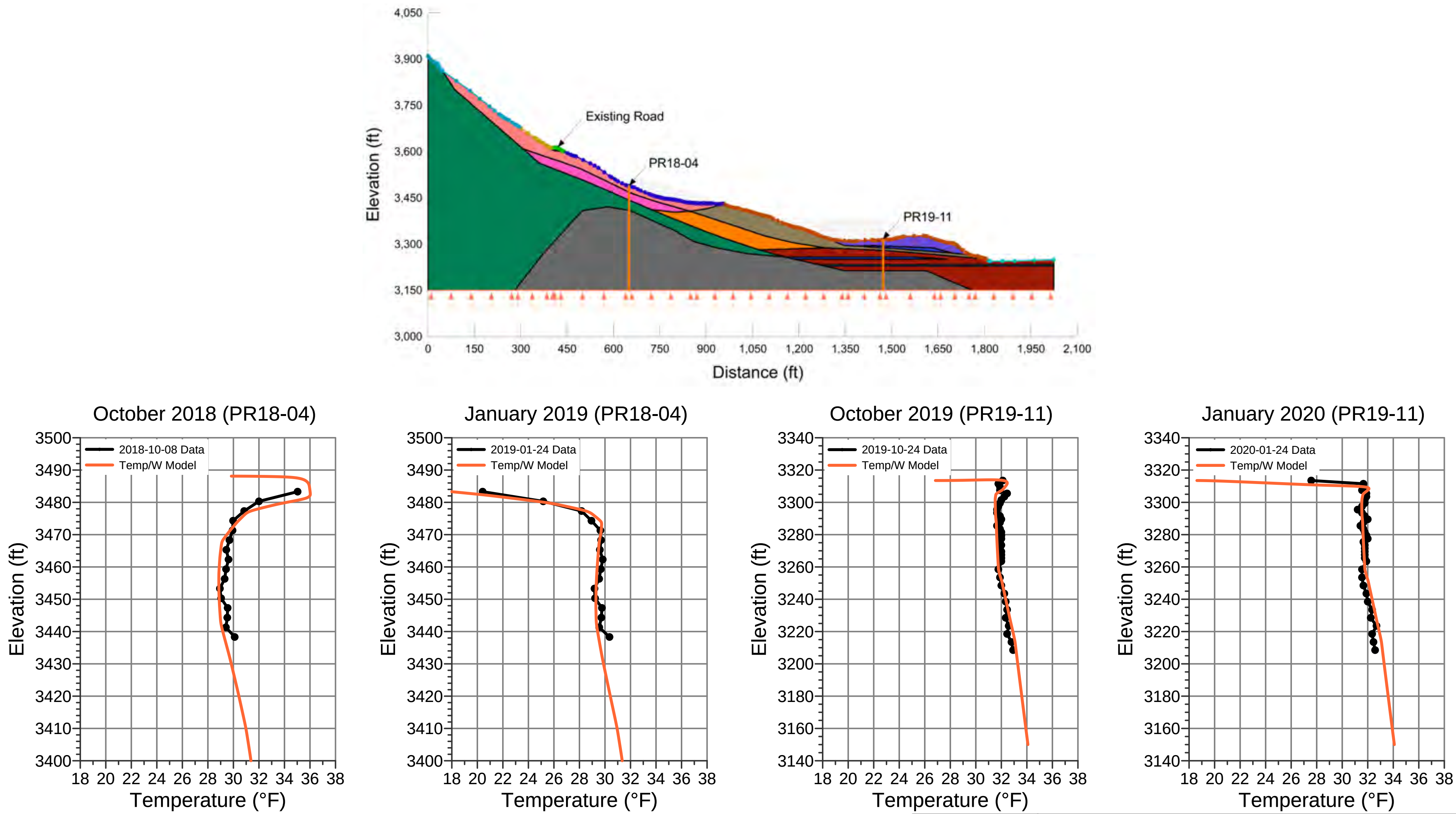

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PREPARED BY: EDG	FIGURE TITLE: CALIBRATION RESULTS FOR SECTION A-A (PR18-04, PR19-11)		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: 3-1

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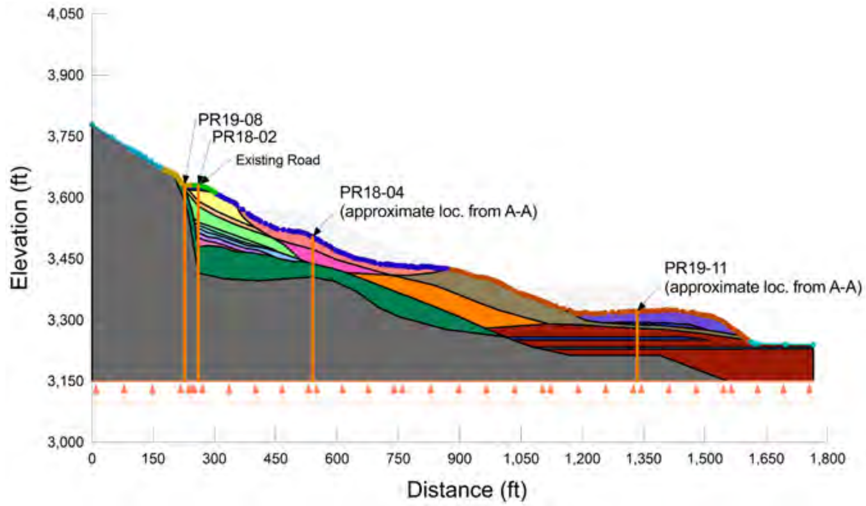

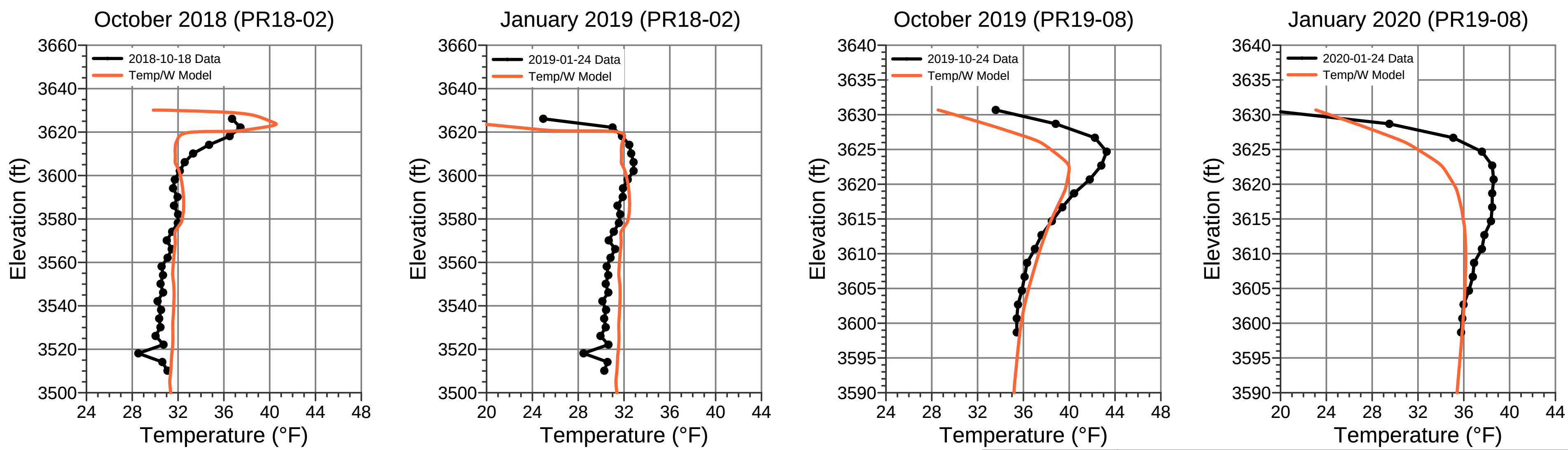

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PREPARED BY: EDG	FIGURE TITLE: CALIBRATION RESULTS FOR SECTION C-C (PR18-02, PR19-08)		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: 3-2

0 5 10 mm in ANSI A sized paper

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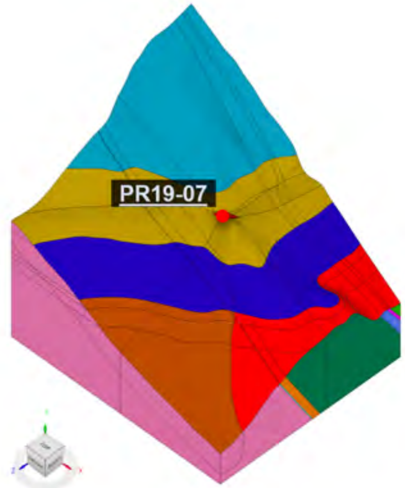

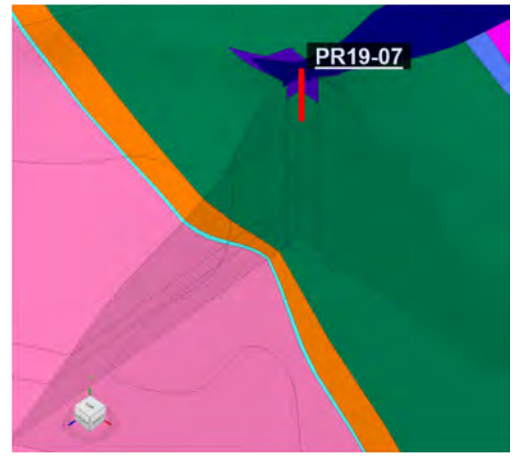

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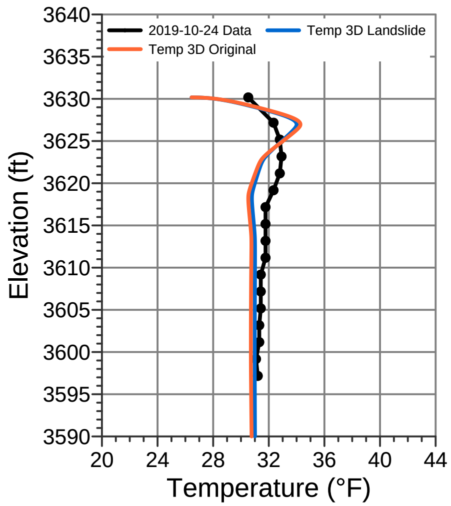

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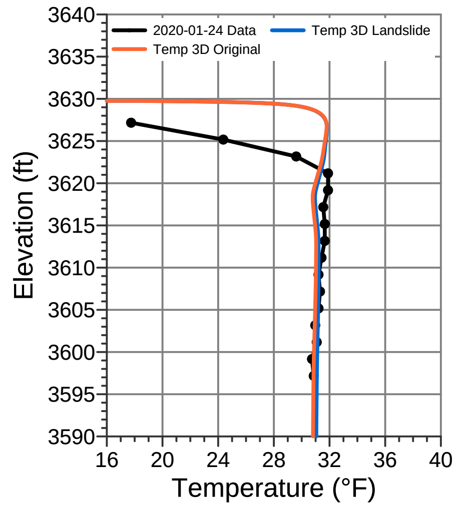

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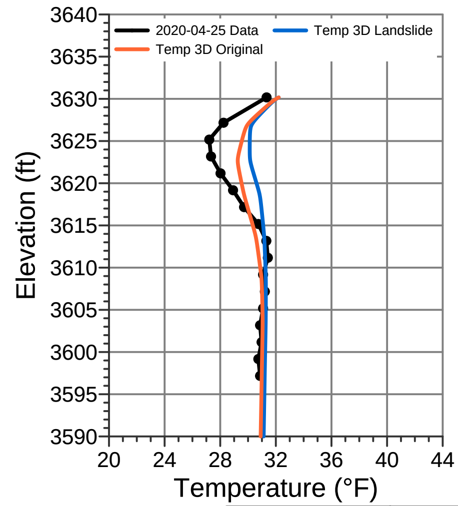

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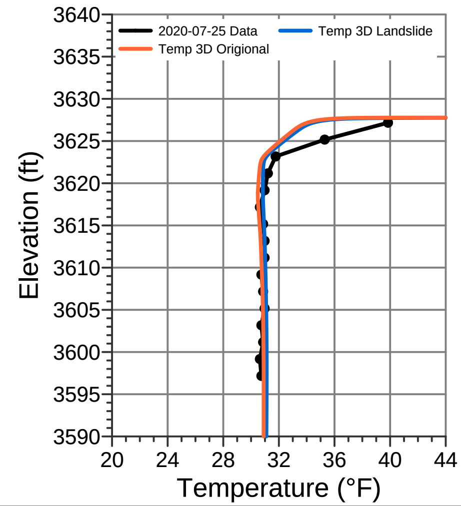

NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
2. IN THE GRAPHS SHOWN, TEMP3D ORIGINAL REFERS TO THE TOPOGRAPHY FROM SEPTEMBER 1, 2021 AND TEMP3D LANDSLIDE REFERS TO AN ESTIMATED NEW TOPOGRAPHY BASED ON IMAGES DATED JANUARY 31, 2022.
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PREPARED BY: EDG

FIGURE TITLE: CALIBRATION RESULTS FOR 3D SECTION (PR19-07)

CHECKED BY: HMB

CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION

APPROVED BY: LUA

SCALE: NTS

PROJECT NO: 2000004

FIGURE NO: 3-3

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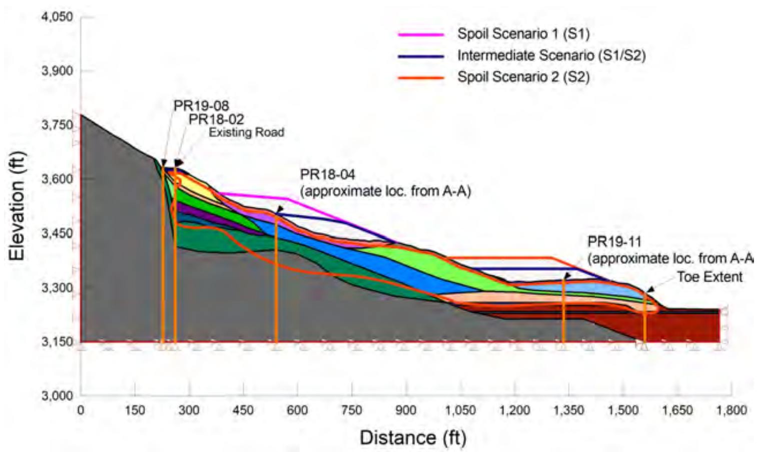

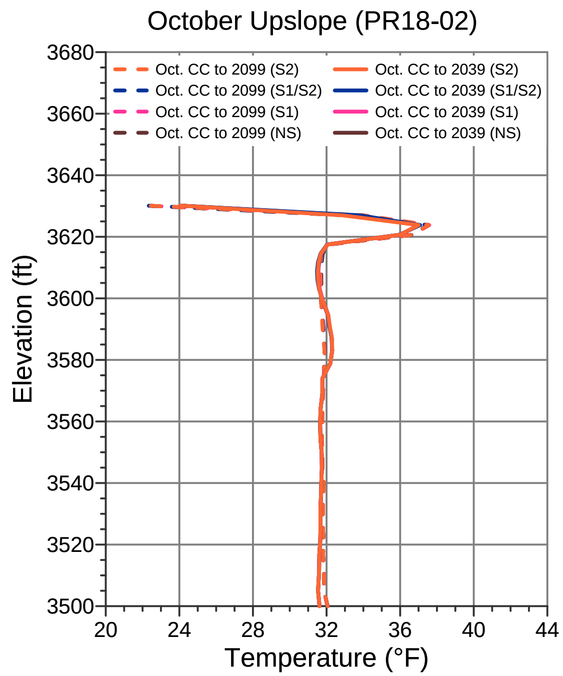

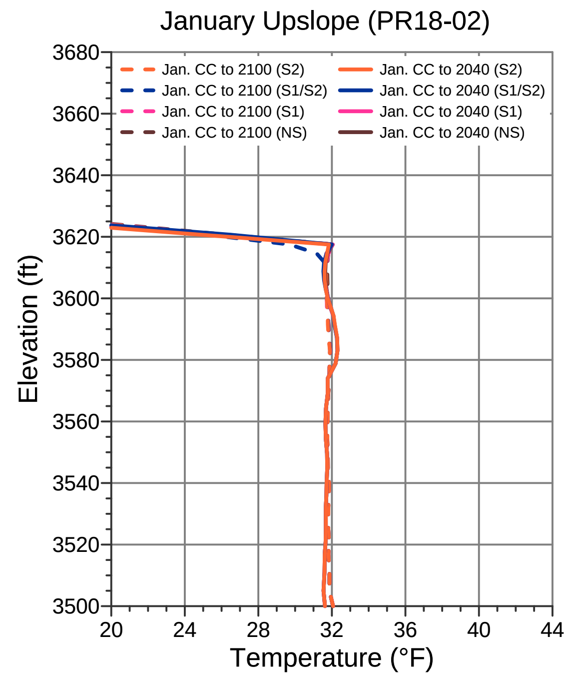

NOTES:

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2. IN THE GRAPHS SHOWN, THE LABELS REFER TO THE MONTH (OCTOBER, JANUARY) AND CLIMATE CHANGE TIME SCALE WITH RESPECT TO THE DIFFERENT SPOIL SCENARIOS. FOR EXAMPLE, OCT. CC TO 2099 (S1) REFERS TO THE TEMPERATURE PROFILE WITH DEPTH OBTAINED IN THE MONTH OF OCTOBER 2099 FOR THE SPOIL SCENARIO S1.
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PREPARED BY: EDG	FIGURE TITLE: SECTION C-C SPOIL PLACEMENT RESULTS UPSLOPE LOCATION		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: 4-1

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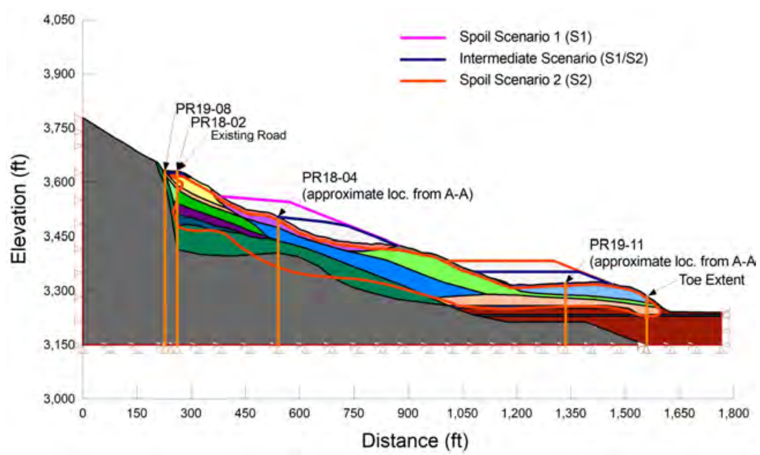

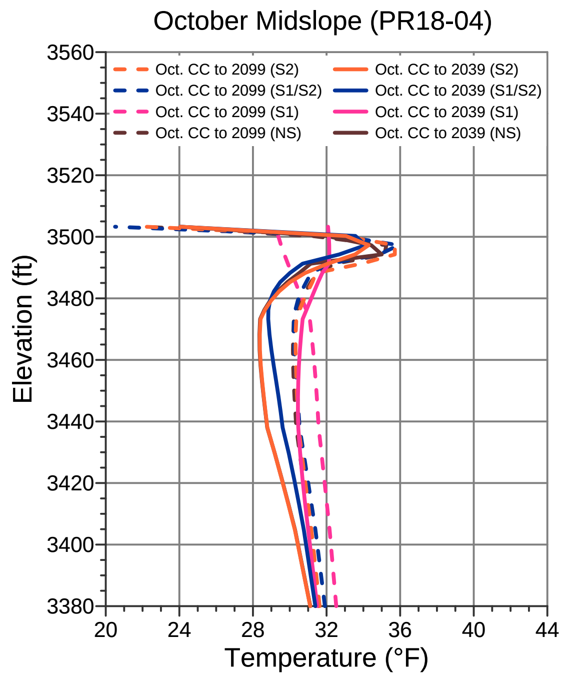

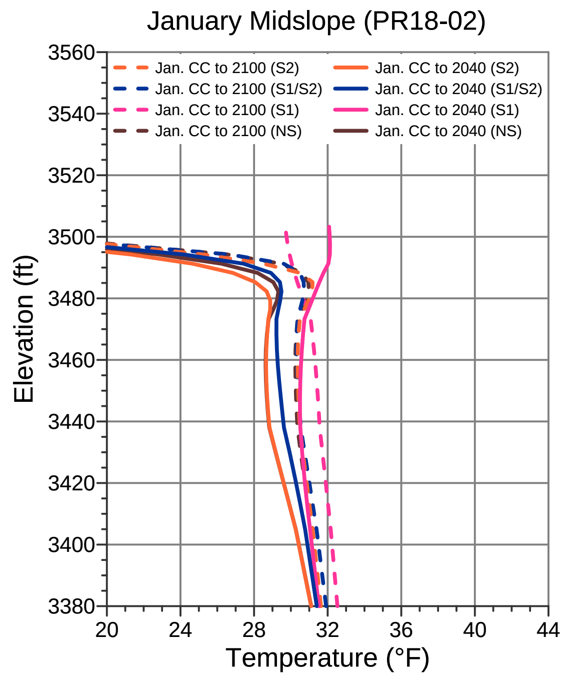

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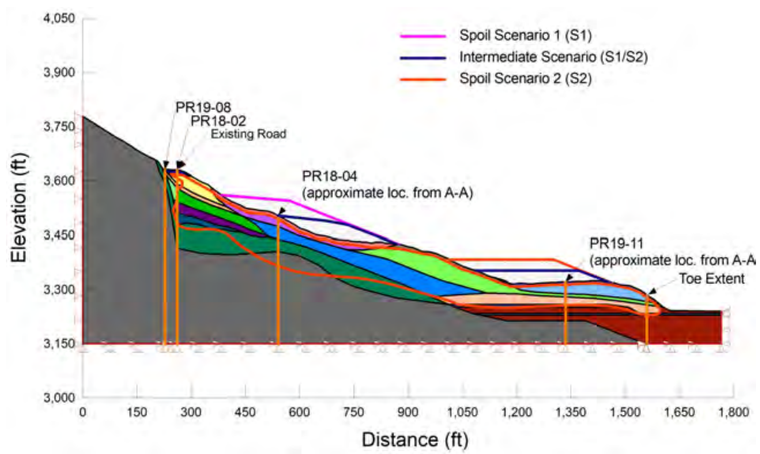
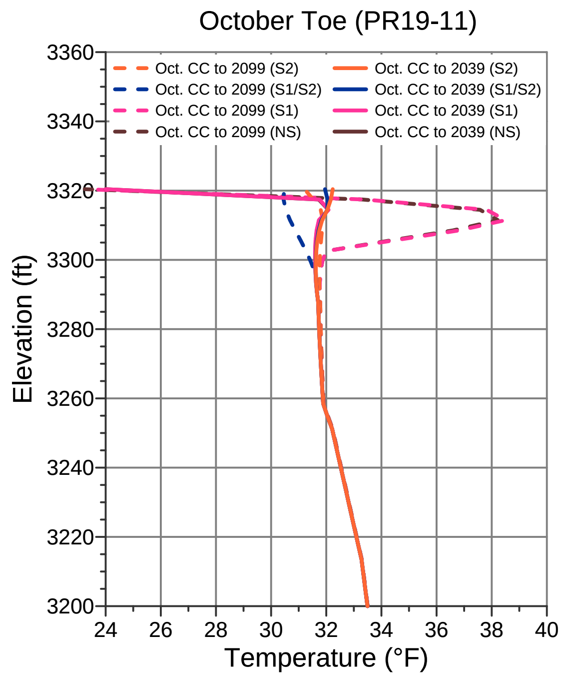
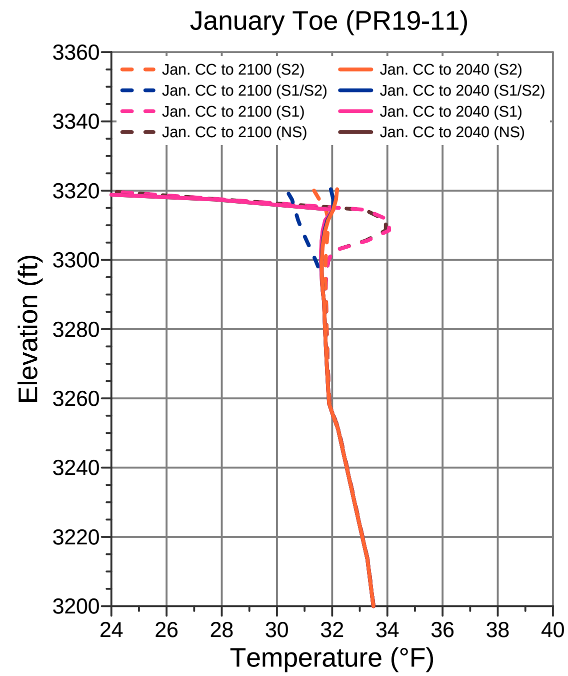
3. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

PREPARED BY:	FIGURE TITLE:		
EDG	SECTION C-C SPOIL PLACEMENT RESULTS MIDSLOPE LOCATION		
CHECKED BY:	CLIENT:		
HMB	WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY:	SCALE:	PROJECT NO:	FIGURE NO:
LUA	NTS	2000004	4-2

0 5 10 mm in ANSI A sized paper







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2. IN THE GRAPHS SHOWN, THE LABELS REFER TO THE MONTH (OCTOBER, JANUARY) AND CLIMATE CHANGE TIME SCALE WITH RESPECT TO THE DIFFERENT SPOIL SCENARIOS. FOR EXAMPLE, OCT. CC TO 2099 (S1) REFERS TO THE TEMPERATURE PROFILE WITH DEPTH OBTAINED IN THE MONTH OF OCTOBER 2099 FOR THE SPOIL SCENARIO S1.
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PREPARED BY: EDG	FIGURE TITLE: SECTION C-C SPOIL PLACEMENT RESULTS TOE LOCATION		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: 4-3

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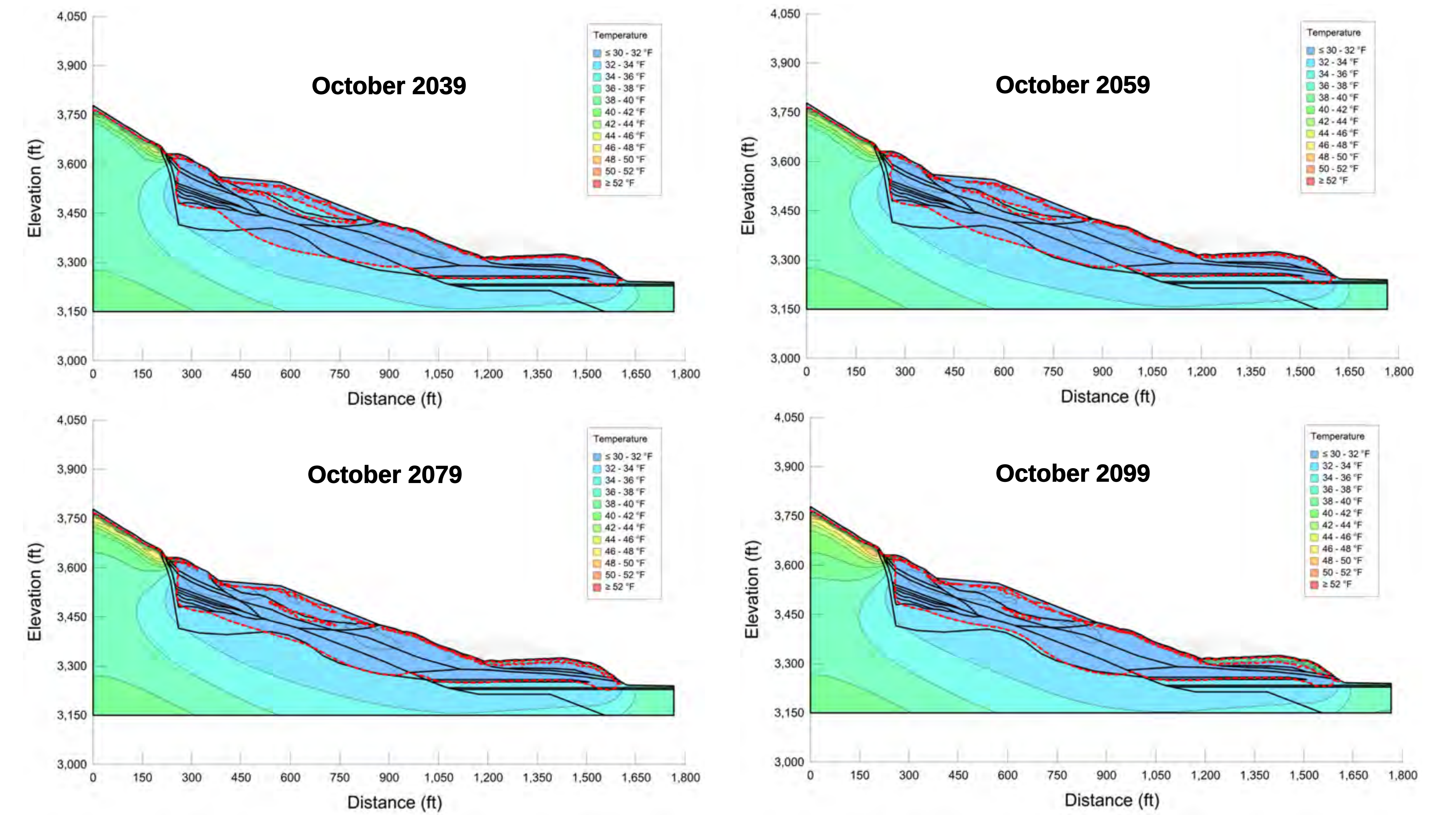

NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
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PREPARED BY: EDG	FIGURE TITLE: ISOTHERM (OCTOBER) FOR S1 AT SECTION C-C
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION
APPROVED BY: LUA	SCALE: NTS / PROJECT NO: 2000004 / FIGURE NO: 4-4

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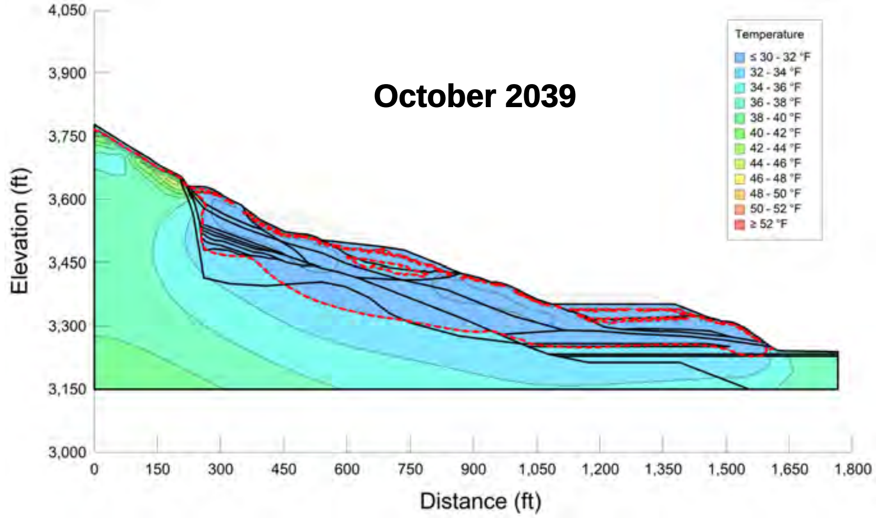

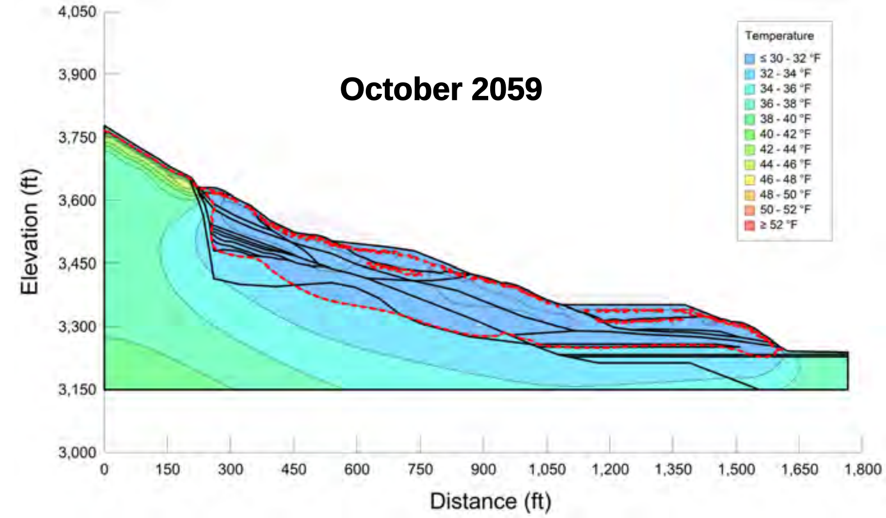

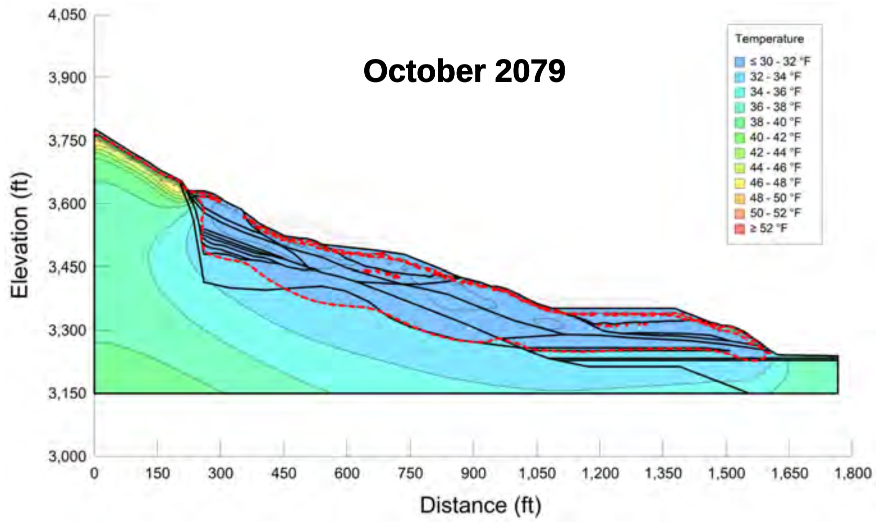

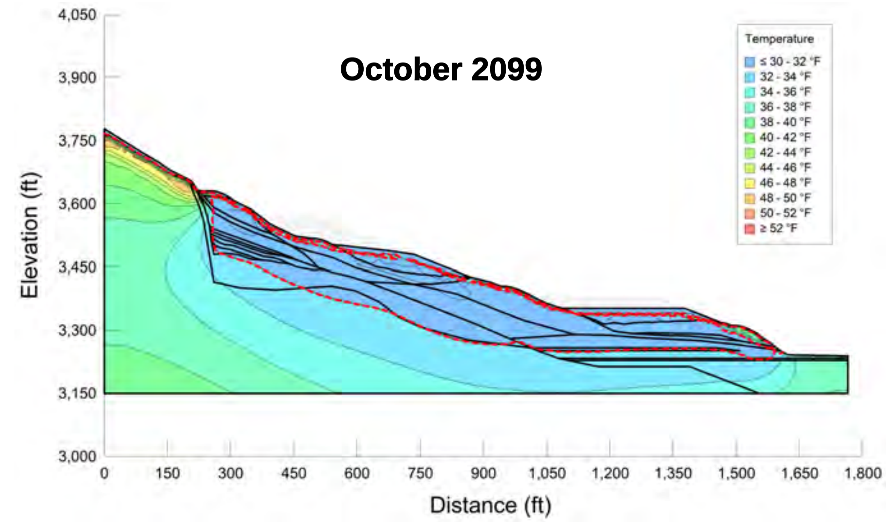

NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
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PREPARED BY:	FIGURE TITLE:		
EDG	ISOTHERM (OCTOBER) FOR S1/S2 AT SECTION C-C		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: 4-5

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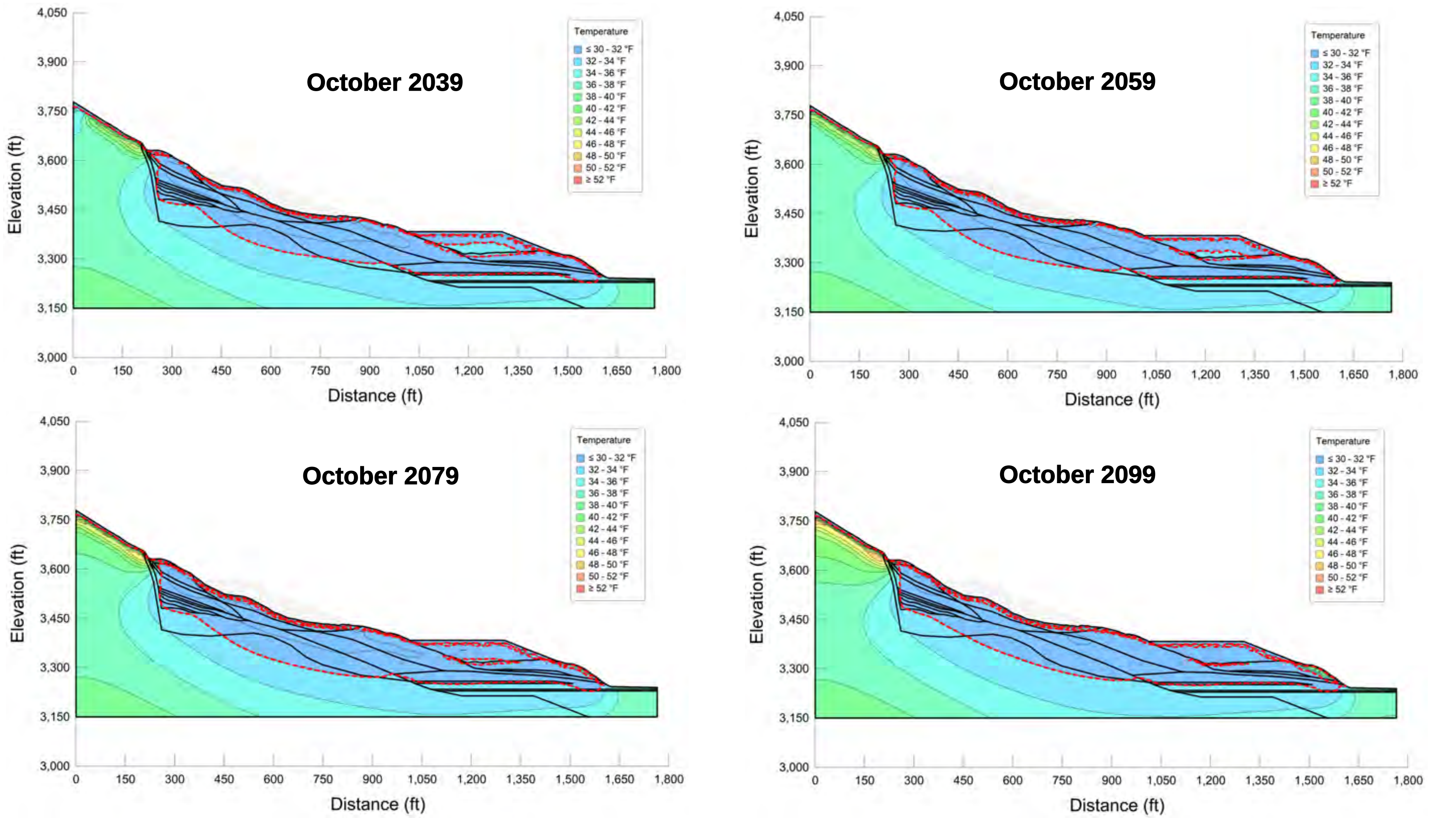

NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
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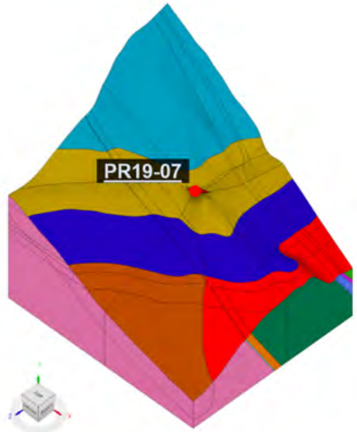
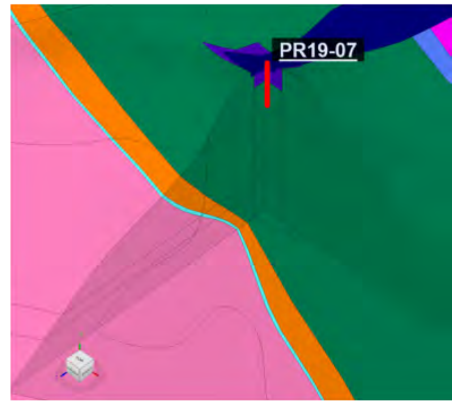
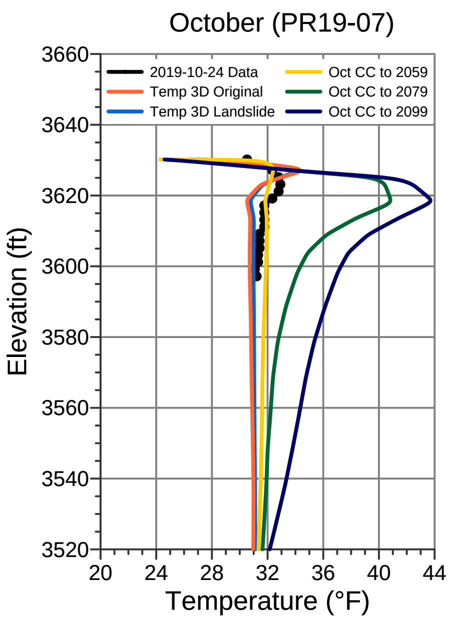
PREPARED BY: EDG	FIGURE TITLE: ISOTHERM (OCTOBER) FOR S2 AT SECTION C-C		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: 4-6

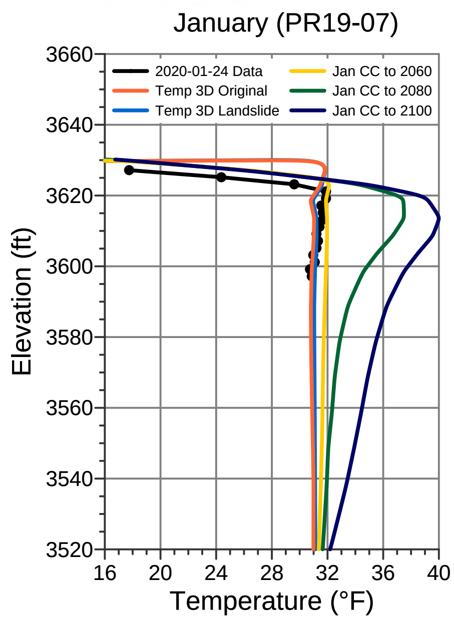
0 5 10 mm in ANSI A sized paper

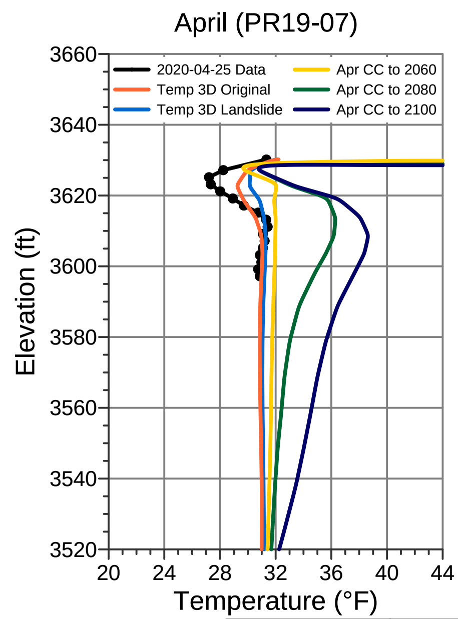
03-2022

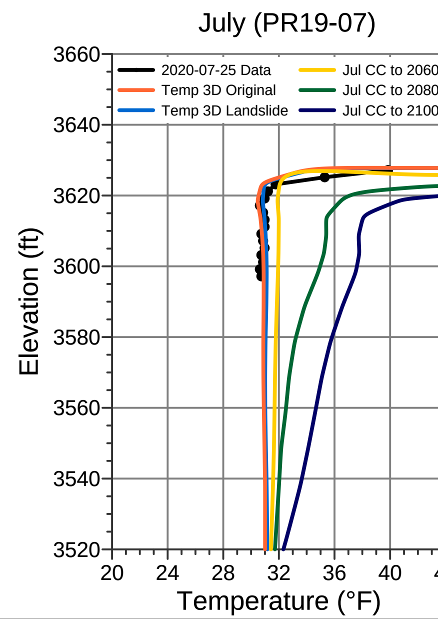












NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
2. IN THE GRAPH LABELS SHOWN, TEMP3D ORIGINAL REFERS TO THE TOPOGRAPHY FROM SEPTEMBER 1, 2021 AND TEMP3D LANDSLIDE REFERS TO AN ESTIMATED NEW TOPOGRAPHY BASED ON IMAGES DATED JANUARY 31, 2022.
3. THE CLIMATE CHANGE MODEL RESULTS ARE LABELED WITH MONTH AND CLIMATE CHANGE TIME SCALE. FOR EXAMPLE, OCT. CC TO 2079 REFERS TO THE TEMPERATURE PROFILE WITH DEPTH OBTAINED IN THE MONTH OF OCTOBER 2079.
4. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

PREPARED BY:	FIGURE TITLE:		
EDG	3D EASTERN ABUTMENT CLIMATE CHANGE RESULTS		
CHECKED BY:	CLIENT:		
HMB	WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY:	SCALE:	PROJECT NO:	FIGURE NO:
LUA	NTS	2000004	4-7

0 5 10 mm in ANSI A sized paper

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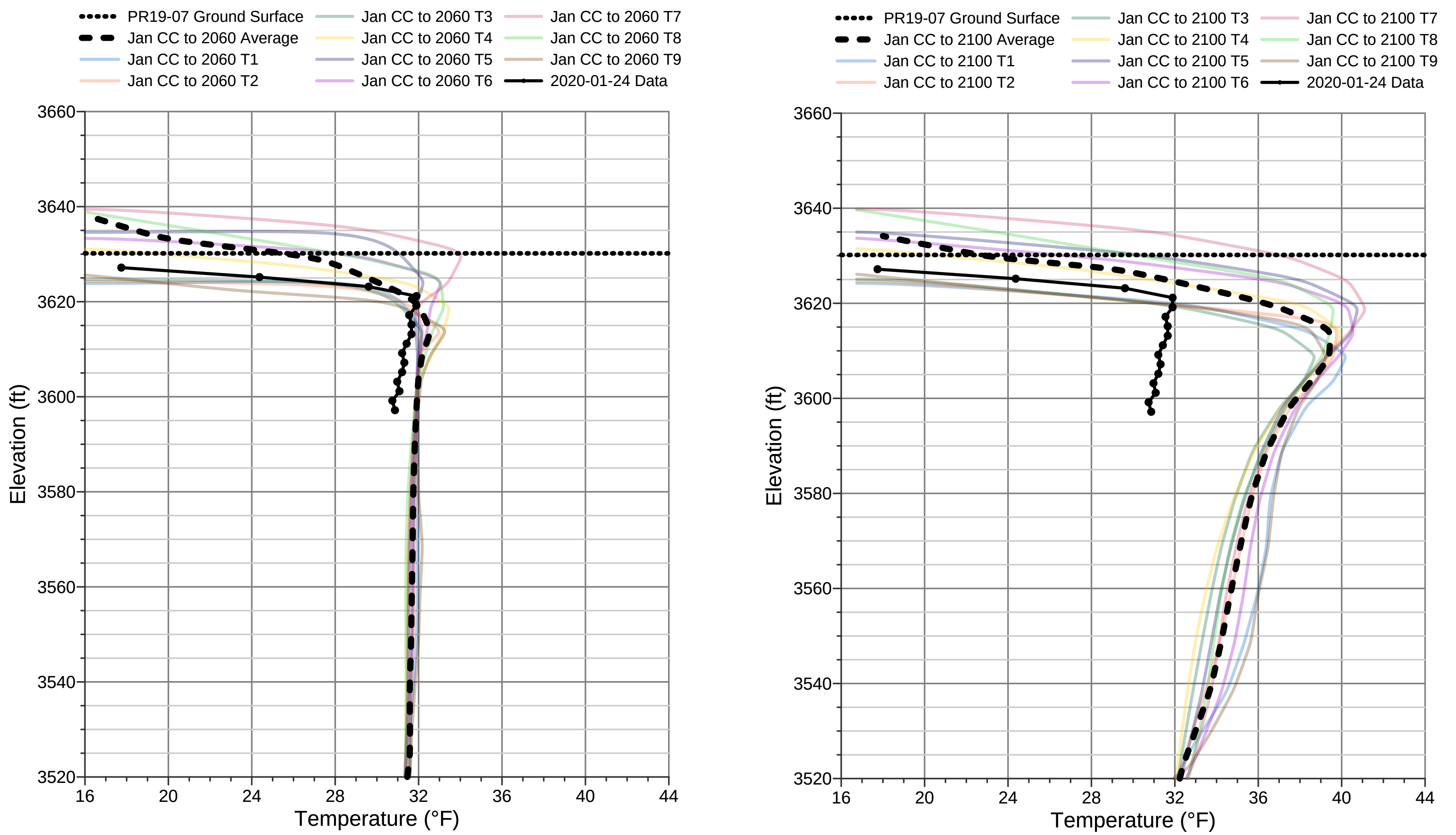

NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
2. THE CLIMATE CHANGE MODEL RESULTS ARE LABELED WITH MONTH, CLIMATE CHANGE TIME SCALE, AND A MONITORING POINT LABEL. FOR EXAMPLE, JAN CC TO 2060 REFERS TO THE TEMPERATURE PROFILE WITH DEPTH OBTAINED IN JANUARY 2060.
3. AVERAGE TEMPERATURE PROFILE WITH DEPTH IS LABELED AS JAN CC TO 2060 AVERAGE AND JAN CC TO 2100 AVERAGE. THESE LINES ARE TAKEN AS THE AVERAGE TEMPERATURE WITH DEPTH FROM THE POINTS SURROUNDING PR19-07. THE ORIGINAL JANUARY 2020 DATA IS ALSO SHOWN FOR COMPARISON.
4. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

PREPARED BY: EDG	FIGURE TITLE: TEMPERATURE WITH DEPTH AROUND ABUTMENT: JANUARY		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: 4-8

0 5 10 mm in ANSI A sized paper

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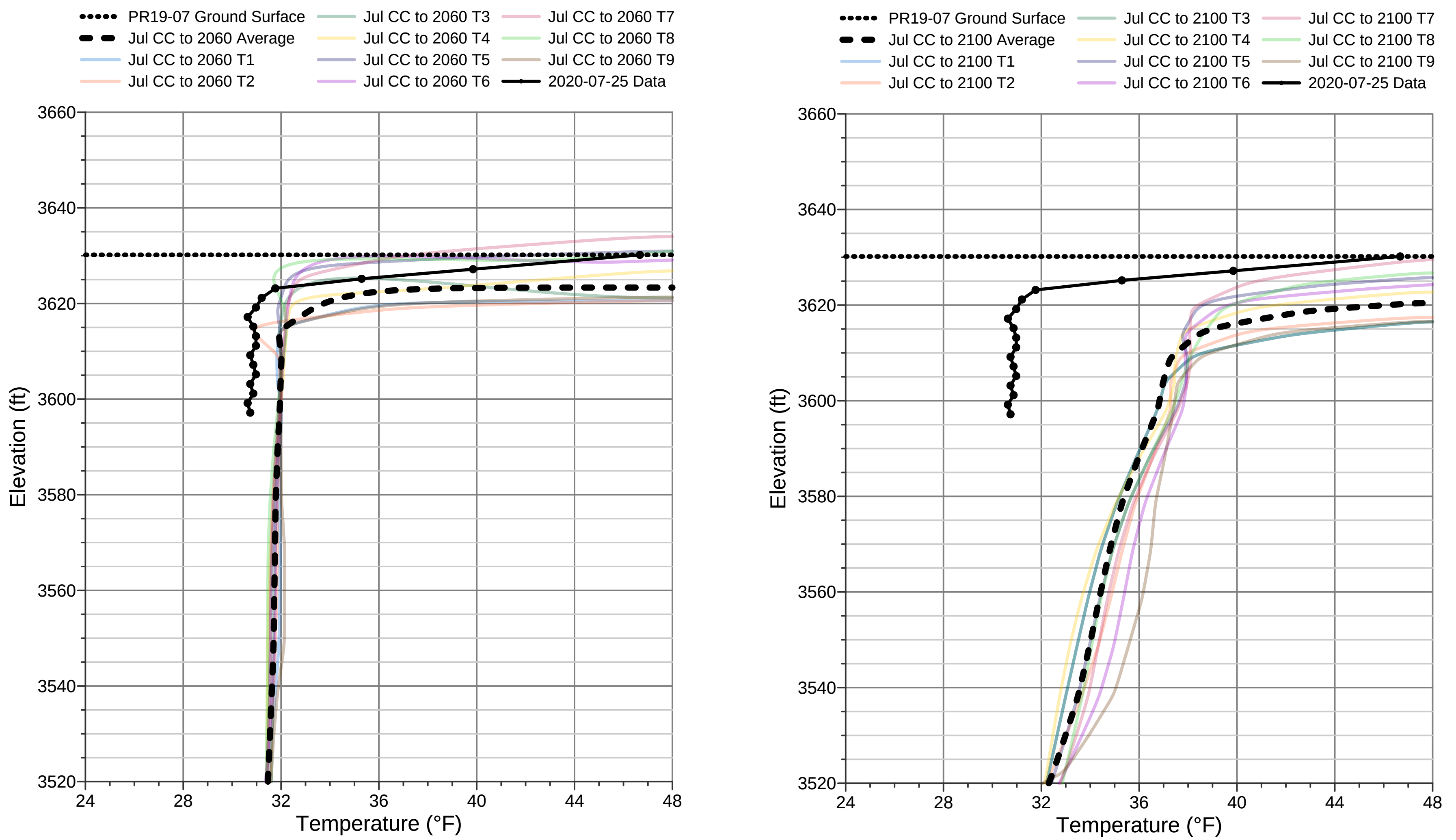


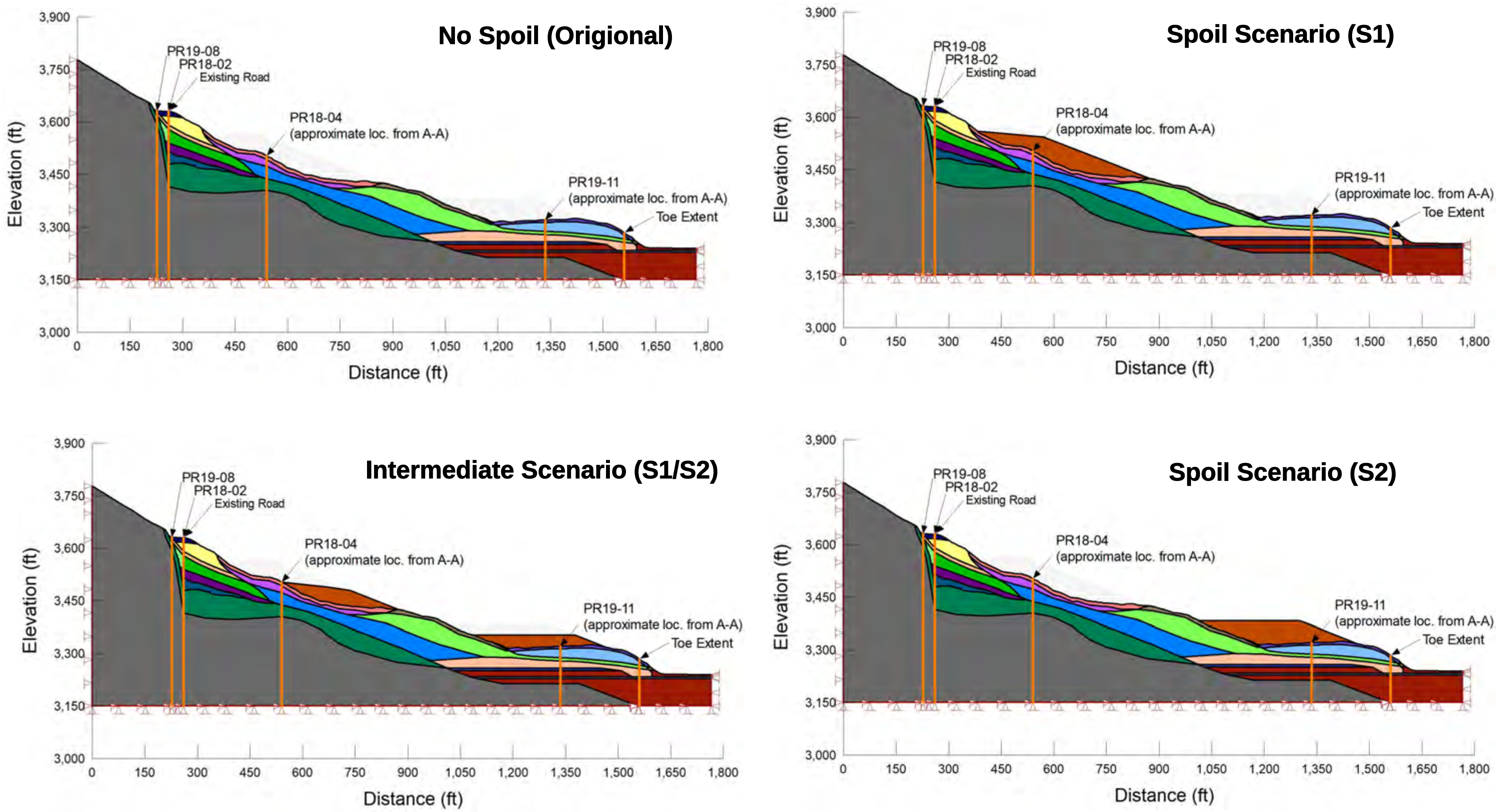
NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
2. THE CLIMATE CHANGE MODEL RESULTS ARE LABELED WITH MONTH, CLIMATE CHANGE TIME SCALE, AND A MONITORING POINT LABEL. FOR EXAMPLE, JUL CC TO 2060 REFERS TO THE TEMPERATURE PROFILE WITH DEPTH OBTAINED IN JULY 2060.
3. AVERAGE TEMPERATURE PROFILE WITH DEPTH IS LABELED AS JUL CC TO 2060 AVERAGE AND JUL CC TO 2100 AVERAGE. THESE LINES ARE TAKEN AS THE AVERAGE TEMPERATURE WITH DEPTH FROM THE POINTS SURROUNDING PR19-07. THE ORIGINAL JULY 2020 DATA IS ALSO SHOWN FOR COMPARISON.
4. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

PREPARED BY:	FIGURE TITLE:		
EDG	TEMPERATURE WITH DEPTH AROUND ABUTMENT: JULY		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: 4-9

0 5 10 mm in ANSI A sized paper

03-2022



NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
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PREPARED BY: EDG	FIGURE TITLE: SPOIL PLACEMENT SCENARIOS FOR SECTION C-C		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: 5-1

0 5 10 mm in ANSI A sized paper

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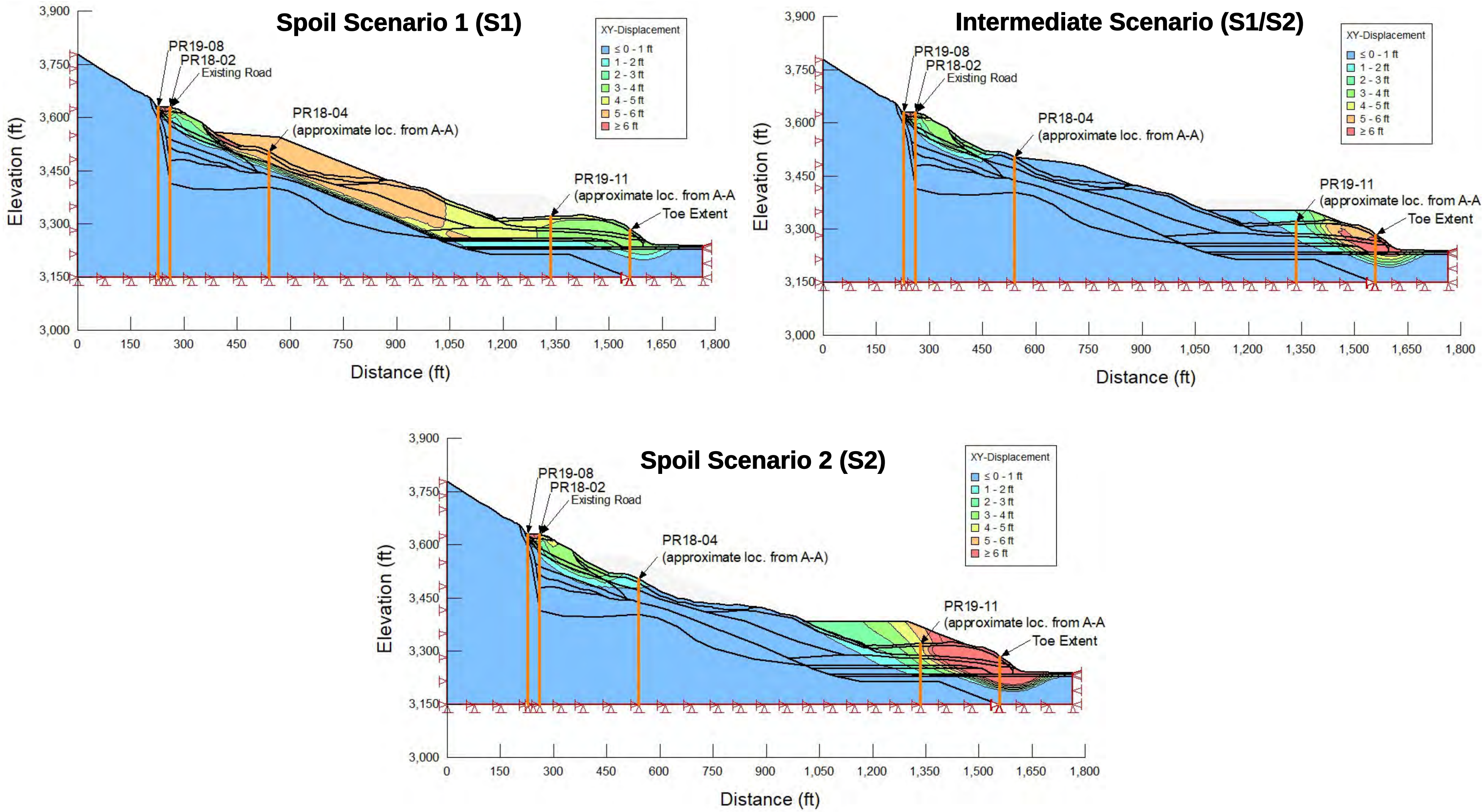

NOTES:
1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
2. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

PREPARED BY: EDG	FIGURE TITLE: XY-DISPLACEMENT CONTOURS FOR SPOIL ADDED AT SECTION C-C		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: 6-1

0 5 10 mm in ANSI A sized paper

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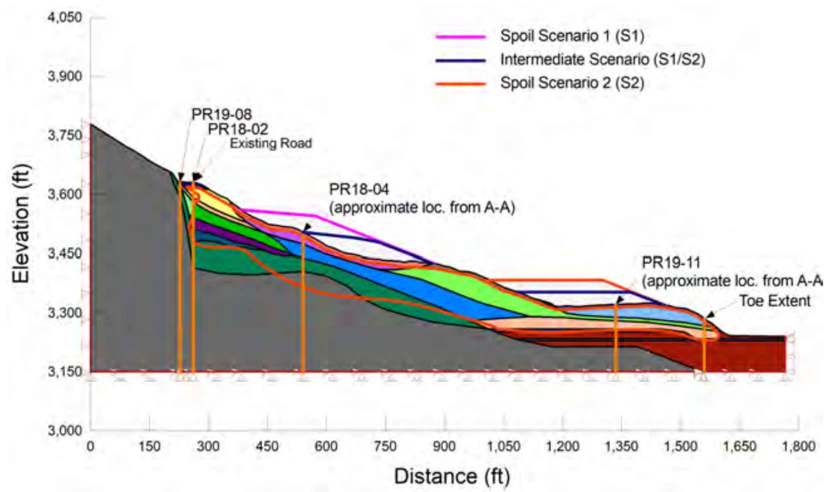

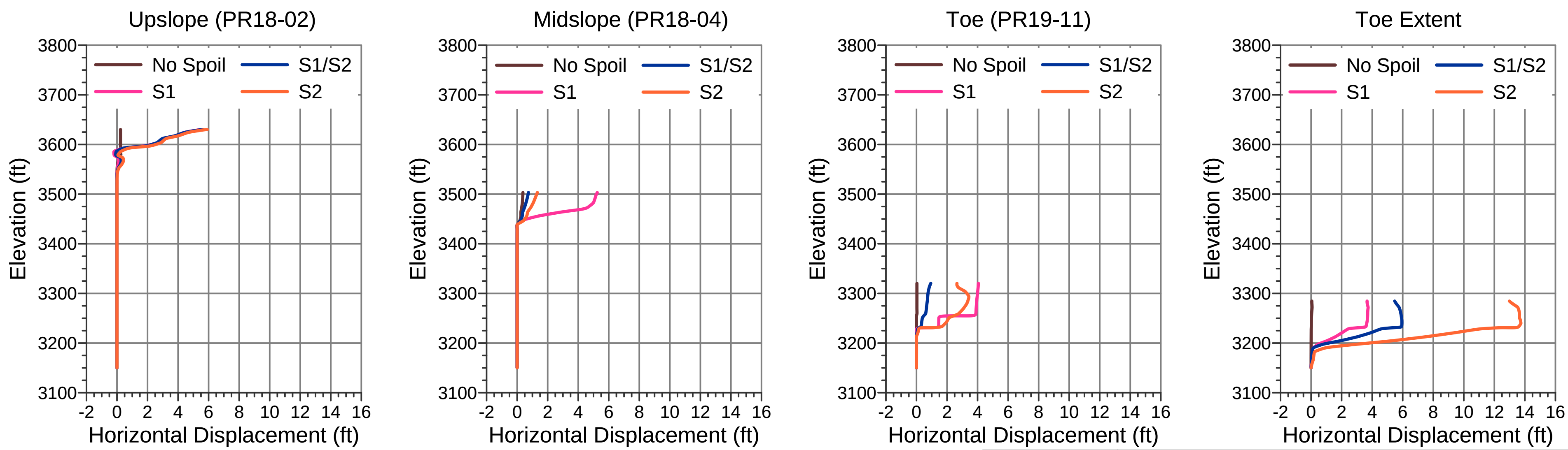

NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
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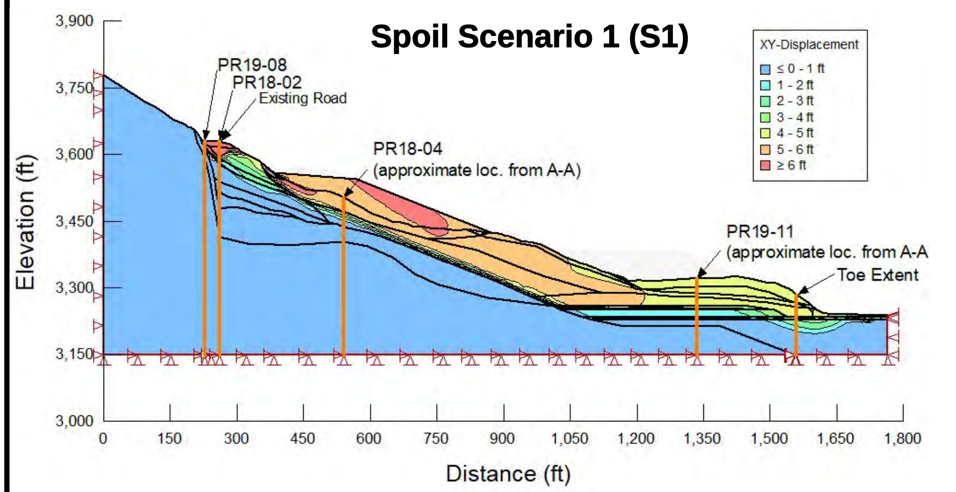
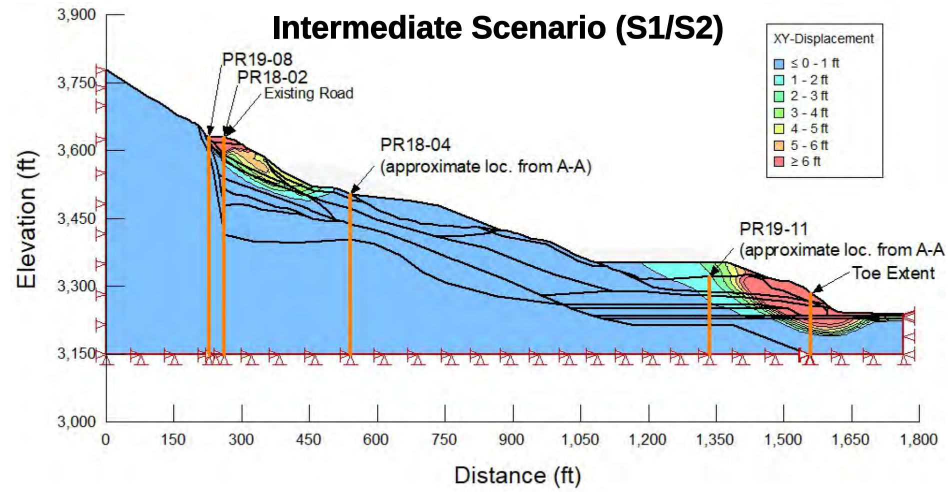
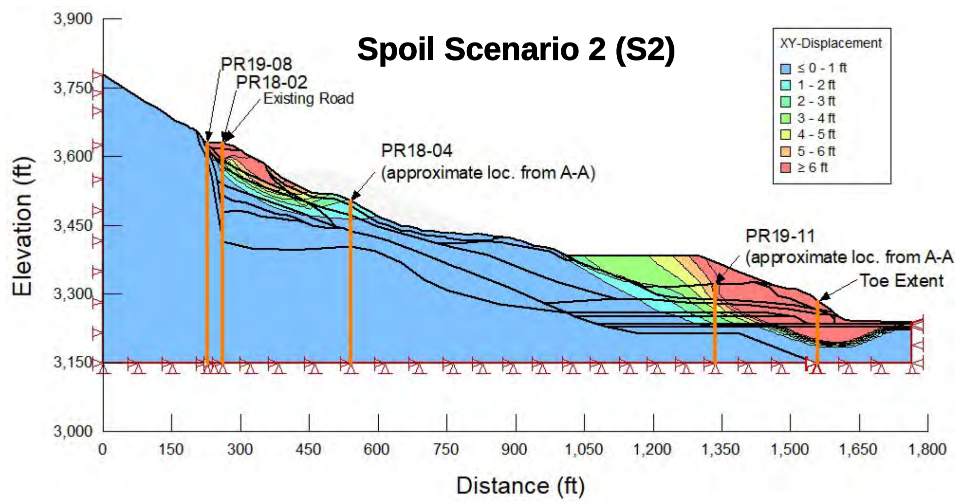
PREPARED BY:	FIGURE TITLE:		
EDG	X-DISPLACEMENT W/ DEPTH FOR SPOIL ADDED AT SECTION C-C		
CHECKED BY:	CLIENT:		
HMB	WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY:	SCALE:	PROJECT NO:	FIGURE NO:
LUA	NTS	2000004	6-2

0 5 10 mm in ANSI A sized paper

03-2022







NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
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PREPARED BY:	FIGURE TITLE:		
EDG	XY-DISPLACEMENT CONTOURS AT YR 2100 AT SECTION C-C		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: 6-3

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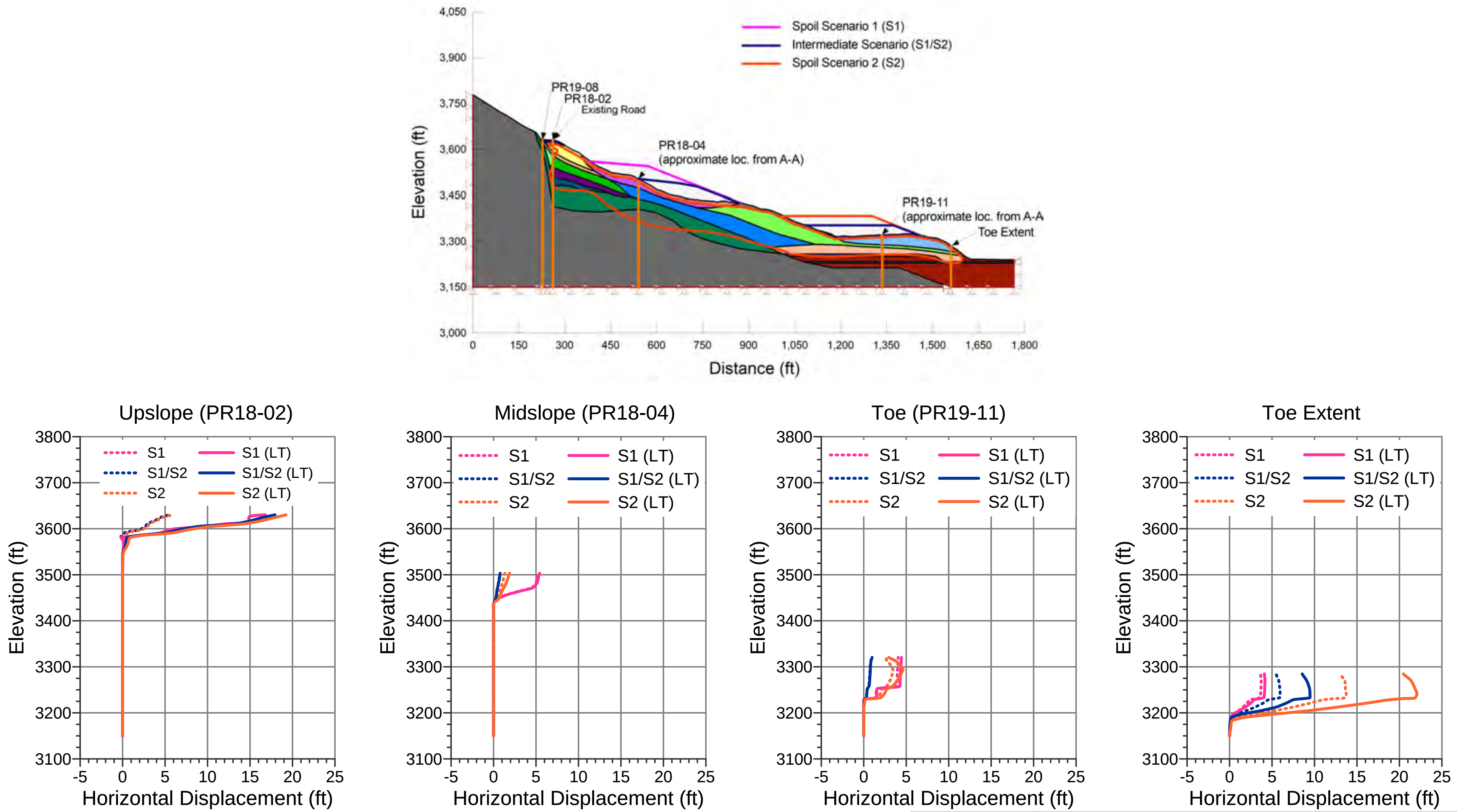

NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
2. IN THE GRAPHS SHOWN, THE SOLID LINES REFER TO THE LONG-TERM DISPLACEMENTS OBTAINED FOR CLIMATE CHANGE PROJECTION AT 2100. THE DASHED LINES REFER TO THE DISPLACEMENTS OBTAINED AT THE TIME OF SPOIL PLACEMENT.
3. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

PREPARED BY: EDG	FIGURE TITLE: X-DISPLACEMENT W/ DEPTH FOR YR 2100 AT SECTION C-C		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: 6-4

0 5 10 mm in ANSI A sized paper

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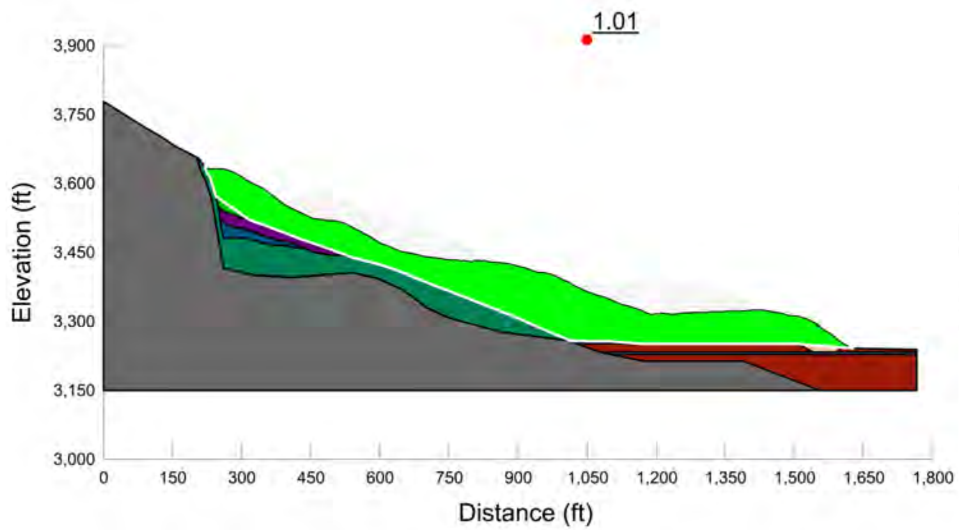
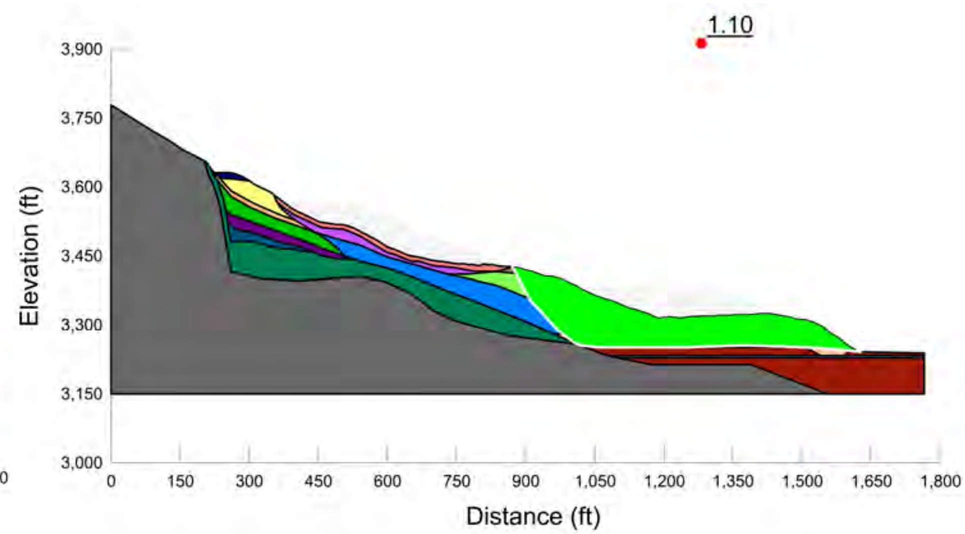
Midslope Slip Surface



Toe Slip Surface



NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
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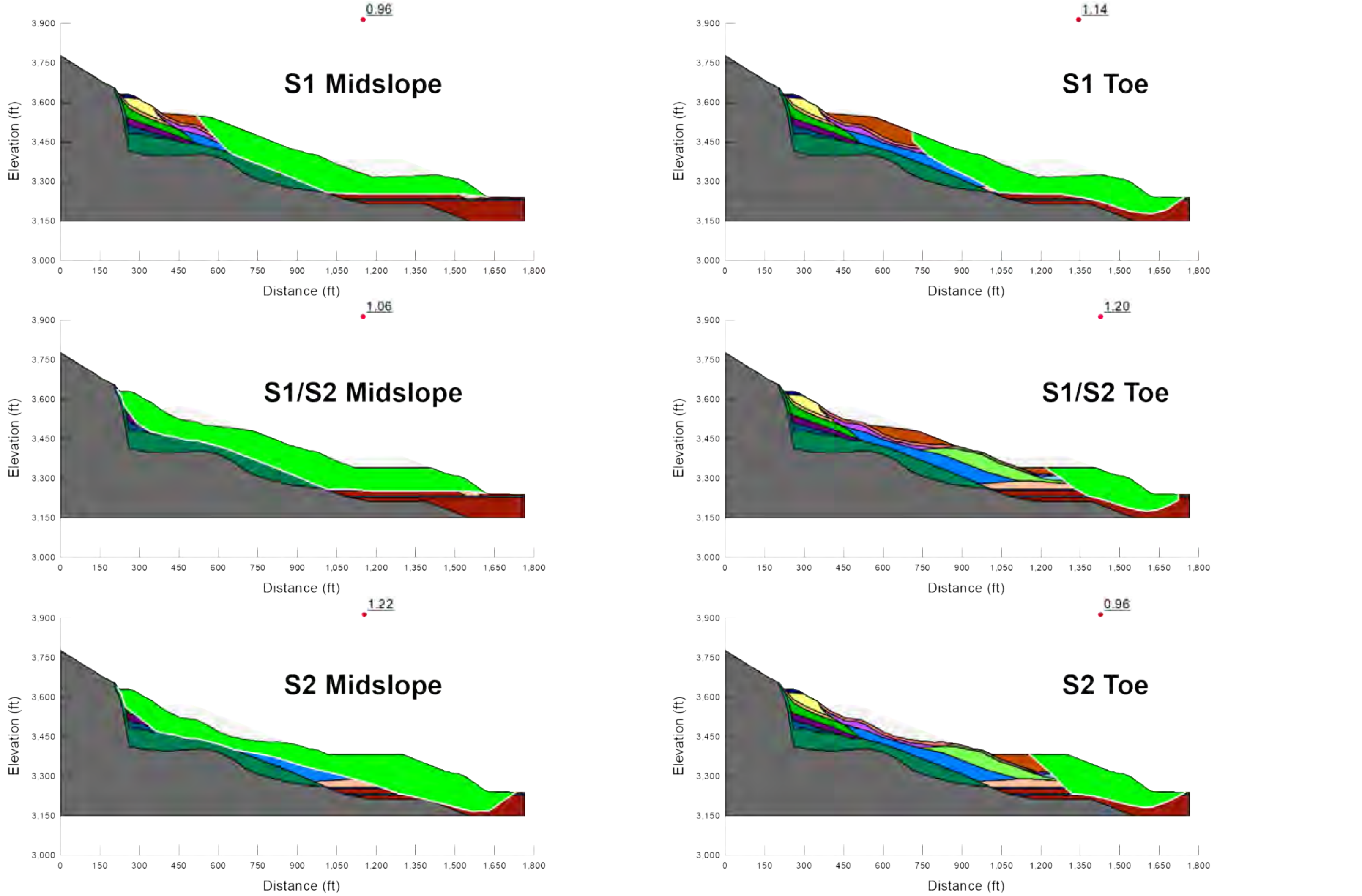
PREPARED BY: EDG	FIGURE TITLE: FoS AND SLIP SURFACES FOR NO SPOIL CASE AT SECTION C-C		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: 6-5



NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
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PREPARED BY: EDG	FIGURE TITLE: FoS AND SLIP SURFACES W/ SPOIL ADDED AT SECTION C-C		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: 6-6

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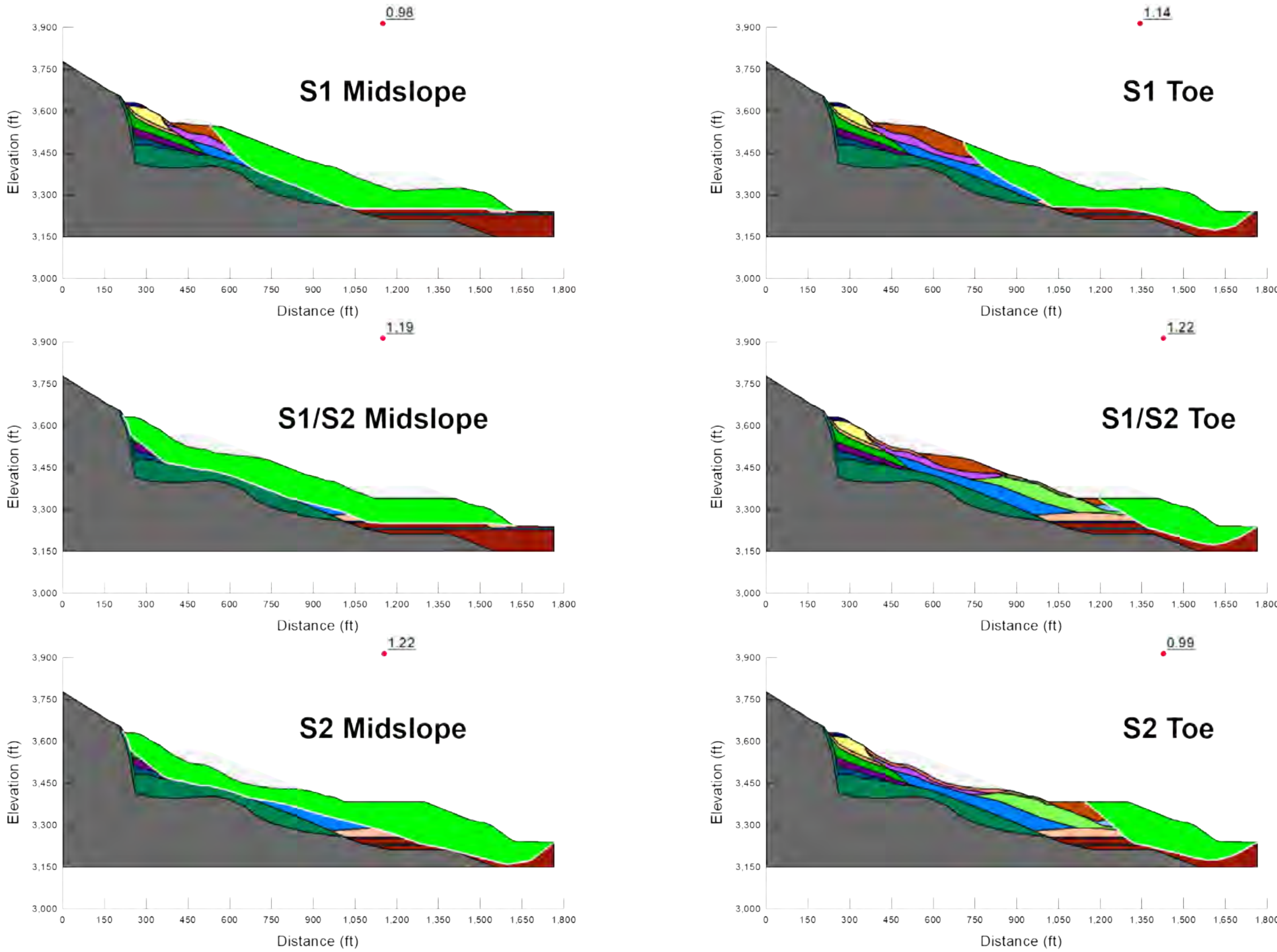

NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.

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PREPARED BY: EDG

FIGURE TITLE: FoS AND SLIP SURFACES FOR YR 2100 AT SECTION C-C

CHECKED BY: HMB

CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION

APPROVED BY: LUA

SCALE: NTS

PROJECT NO: 2000004

FIGURE NO: 6-7

0 5 10 mm in ANSI A sized paper

APPENDIX A
BOREHOLE LOGS

Descriptive Terminology for Boring Logs

Field descriptions of borings are based on the FLH Soil and Rock Description and Identification Guidelines that generally follow the Visual-Manual Procedure (ASTM D 2488). The soil classifications shown on the boring logs are based on laboratory tests (ASTM D 2487) when the two-letter group symbol follows the group name in parenthesis.

U.S. Department of Transportation
Federal Highway Administration

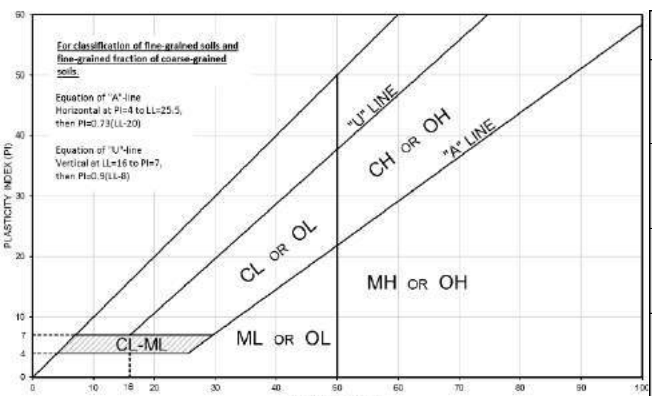
SOIL CLASSIFICATION CHART

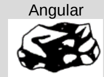
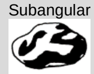
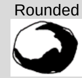
Criteria for Assigning Group Symbols and Group Name Using Laboratory Tests[A]				Group Symbol	Group Name[B]
COARSE-GRAINED SOILS More than 50% retained on No. 200 Sieve	**GRAVELS** More than 50% of coarse fraction retained on No. 4 Sieve	**Clean GRAVELS** Less than 5% fines [E]	Cu ≥ 4 and 1 ≤ Cc ≤ 3[C]	GW	Well-graded GRAVEL [D]
			Cu < 4 and/or 1 > Cc > 3 [C]	GP	Poorly-graded GRAVEL [D]
		GRAVELS with fines More than 12% fines [E]	Fines classify as ML or MH	GM	Silty GRAVEL [D,F]
			Fines classify as CL or CH	GC	Clayey GRAVEL [D,F]
	SANDS Less than 50% retained on No. 4 Sieve	**Clean SANDS** Less than 5% fines [I]	Cu ≥ 6 and 1 ≤ Cc ≤ 3 [C]	SW	Well-graded SAND [H]
			Cu < 6 and/or 1 > Cc > 3 [C]	SP	Poorly-graded SAND [H]
		SANDS with fines More than 12% fines [I]	Fines classify as ML or MH	SM	Silty SAND [F,H]
			Fines classify as CL or CH	SC	Clayey SAND [F,H]
FINE-GRAINED SOILS 50% or more passes the No. 200 Sieve	**SILTS and CLAYS** Liquid limit less than 50	Inorganic	PI > 7 and plots on or above the “A” line [J]	CL	Lean CLAY [K,L,M]
			PI < 4 or plots below “A” line [J]	ML	SILT [K,L,M]
		Organic	Liquid limit – oven dried / Liquid limit – not dried < 0.75	OL	Organic CLAY [K,L,M,N] Organic SILT [K,L,M,O]
	SILTY and CLAYS Liquid limit 50 or more	Inorganic	PI plots on or above “A” line	CH	Fat CLAY [K,L,M]
			PI plots below “A” line	MH	Elastic SILT [K,L,M]
		Organic	Liquid limit – oven dried / Liquid limit – not dried < 0.75	OH	Organic CLAY [K,L,M,P] Organic SILT [K,L,M,Q]
HIGHLY ORGANIC SOILS	Primarily organic matter, dark in color, and organic odor			PT	PEAT

[A] Based on material passing the 3-inch sieve.
[B] If field sample contains cobbles or boulders, add “with cobbles” or “boulders” or both, to group name.
[C] $Cu = D_{60}/D_{10}$ $Cc = (D_{30})^2 / (D_{10} \times D_{60})$
[D] If soil contains ≥15% sand, add “with sand” to group name.
[E] Gravels with 5 to 12% fines require dual symbols:
GW-GM well-graded GRAVEL with silt
GW-GC well-graded GRAVEL with clay
GP-GM poorly-graded GRAVEL with silt
GP-GC poorly-graded GRAVEL with clay

[F] If fines classify as CL-ML, use dual symbol GC-GM or SC-SM
[G] If fines are organic, add “with organic fines” to group name.
[H] If soil contains ≥15% gravel, add “with gravel” to group name.
[I] Sand with 5 to 12% fines require dual symbols:
SW-SM well-graded SAND with silt
SW-SC well-graded SAND with clay
SP-SM poorly-graded SAND with silt
SP-SC poorly-graded SAND with clay
[J] If Atterberg limits plot in hatched area, soil is a CL-ML, silty CLAY.

[K] If soil contains 15 to 29% plus No. 200, add “with sand” or “with gravel”, whichever is predominant.
[L] If soil contains ≥ 30% plus No. 200, predominantly sand, add “sandy” to beginning of group name.
[M] If soil contains ≥ 30% plus No. 200, predominantly gravel, add “gravelly” to beginning of group name.
[N] PI ≥ 4 and plots on or above “A” line.
[O] PI < 4 or plots below “A” line.
[P] PI plots on or above “A” line.
[Q] PI plots below “A” line.



ANGULARITY OF COARSE-GRAINED SOILS	
Angular 	Sharp edges and relatively plane sides with unpolished surfaces
Subangular 	Similar to angular description, but with rounded edges
Subrounded 	Nearly plane sides, but will have well-rounded corners and edges.
Rounded 	Smoothly curved sides and no edges

PARTICLE SIZE OF COARSE-GRAINED SOILS	
Component	**Grain Size Limits**
Boulders	> 12” (> 300 mm)
Cobbles	3 – 12” (75 – 300 mm)
Coarse Gravel	3/4 - 3" (19 - 75 mm)
Fine Gravel	#4 Sieve - 3/4" (4.75 - 19 mm)
Coarse Sand	#10 - #4 Sieve (2.00 - 4.75 mm)
Medium Sand	#40 - #10 Sieve (0.425 - 2.00 mm)
Fine Sand	#200 - #40 Sieve (0.075 - 0.425 mm)

Standard Penetration Test (SPT): the SPT consists of driving a 2 in (50 mm) O.D. split barrel sampler a depth of 18 in (450 mm) or 24 in (600 mm) using a 140 lb (63.6 kg) hammer with a 30 in (750 mm) drop. The blow count is the number of blows recorded for each 6 inch (50 mm) increment. The N-value is the total number of blows for the second and third increments. Note that the N-values shown on the boring logs do not include any corrections for non-standard sampler size, hammers, drill rods, etc.

SOIL STRUCTURE TERMS	
Stratified	Alternating layers of varying material or color with layers > 1/4 inch (6 mm), note thickness and inclination.
Laminated(1)	Alternating layers of varying material or color with layers < 1/4 inch (6 mm), note thickness and inclination.
Fissured(1)	Breaks along definite planes of fracture with little resistance to fracturing.
Slickensided(1)	Fracture planes appear polished or glossy, sometimes striated.
Blocky(1)	Cohesive soil that can be broken down into smaller angular lumps which resists further breakdown.
Disrupted	Soil structure is broken and mixed. Infers that material has moved substantially - landslide debris.
Homogeneous	Same color and appearance throughout.
Lensed	Inclusion of small pockets of different soil, such as small lenses of sand scattered through a mass of clay; < 1/4 inch (6 mm) note thickness.

(1) Do not use laminated, fissured, slickensided, or blocky for coarse-grained soils.

APPARENT DENSITY OF COARSE-GRAINED SOIL	
SPT N-value (blows per foot)	**Apparent Density**
0 to 4	Very Loose
5 to 10	Loose
11 to 30	Medium Dense
31 to 50	Dense
> 50	Very Dense

CONSISTENCY OF FINE-GRAINED SOIL	
SPT N-value (blows per foot)	**Consistency**
0 to 1	Very Soft
2 to 4	Soft
5 to 8	Firm
9 to 15	Stiff
16 to 30	Very Stiff
> 30	Hard

GRAIN/CRYSTAL SIZE FOR ROCKS (MODIFIED AFTER WENTWORTH, 1972)		
Grain Size	**Description**	**Criteria**
Less than 0.003 inches (<0.075 mm)	Very fine grained	Cannot be distinguished by unaided eye. Few to no mineral grains are visible with a hand lens.
0.003 to 0.02 inches (0.075 to 0.425 mm)	Fine grained	Few grain/crystal boundaries are visible; grains can be distinguished with difficulty by the unaided eye but can be somewhat distinguished by hand lens.
0.02 to 0.08 inches (0.425 to 2 mm)	Medium grained	Most grain/crystal boundaries are visible; grains distinguishable by eye and with the aid of a hand lens.
0.08 to 0.2 inches (2 to 4.75 mm)	Coarse grained	Grain/crystal boundaries are visible; grains distinguishable with the naked eye and hand lens.
Greater than 0.2 inches (>4.75 mm)	Very coarse grained	Grain/crystal boundaries are Clearly visible; grains are distinguishable with the naked eye.

DEGREE OF WEATHERING		
Term	**Description**	**Grade**
Fresh	No visible sign of rock material weathering; slight discoloration on major discontinuity surface is possible.	I
Slightly Weathered	Discoloration indicates weathering of rock material and discontinuity surfaces. All rock material may be discolored by weathering and the external surface may be somewhat weaker than in its fresh condition.	II
Moderately Weathered	Less than half the rock material is decomposed and/or disintegrated to a soil. Fresh or discolored rock is present either as a discontinuous framework or as corestones. A minimum 2-inch (50 mm) diameter sample *cannot* be broken readily by hand across the rock fabric.	III
Highly Weathered	More than half of the rock is decomposed and/or disintegrated to soil. Fresh or discolored rock is present either as a discontinuous framework or as corestones. A minimum 2-inch (50 mm) diameter sample *can* be broken readily by hand across the rock fabric.	IV
Completely Weathered	All rock material is decomposed and/or disintegrated to soil. The original mass structure is still largely intact. Material can be granulated by hand. ***If rock is considered to be completely weathered, use FLH Soil Description and Identification Guidelines to describe the residual soil material.***	V
Residual Soil	All rock material is converted to soil. The mass structure and material fabric are destroyed but the apparent structure remains intact. There may be a large change in volume, but the soil has not been significantly transported. Material can be easily broken-down by hand. ***If rock is considered to be completely weathered, use FLH Soil Description and Identification Guidelines to describe the residual soil material.***	VI

RELATIVE STRENGTH OF INTACT ROCK SPECIMENS (ISRM, 1978 &1981)			
Grade	**Description**	**Field Indentificaiton**	**Approximate Uniaxial Compressive Strength**
R0	Extremely Weak Rock	Specimen can be indented by thumbnail	35 - 150 psi (250 - 1,000 kPa)
R1	Very Weak Rock	Specimen crumbles under sharp blow with point of geological hammer, and can be peeled with a pocket knife.	150 - 725 psi (1,000 - 5,000 kPa)
R2	Weak Rock	Shallow cuts or scrapes can be made in a specimen with a pocket knife. A firm blow with a geological hammer point creates shallow indents.	725 - 3,500 psi (5,000 - 25,000 kPa)
R3	Medium Strong Rock	Specimen cannot be scraped or cut with a pocket knife. Specimen can be fractured with a single firm blow with a geologic hammer point.	3,500 - 7,250 psi (25,000 - 50,000 kPa)
R4	Strong Rock	Specimen requires more than one firm blow of the geologic hammer point to fracture.	7,250 - 14,500 psi (50,000 - 100,000 kPa)
R5	Very Strong Rock	Specimen requires many firm blows from the hammer end of the geologic hammer to fracture.	14,500 - 36,250 psi (100,000 - 250,000 kPa)
R6	Extremely Strong Rock	Specimen can only be chipped with firm blows from the hammer end of the geologic hammer.	>36,250 psi (>250,000 kPa)

DISCONTINUITY CONDITION (ISRM, 1978, 1981)	
Condition	**Description**
Excellent Condition	Very rough surfaces, no separation, hard discontinuity wall (>R2).
Good Condition	Slightly rough surfaces, separation less than ~0.04 inches (1 mm), hard discontinuity wall (>R2).
Fair Condition	Slightly rough surface, separation greater than ~0.04 inches (1 mm), soft discontinuity wall (<R3).
Poor Condition	Slickensided surfaces, or soft gouge less than ~0.2 inches (5 mm) thick, or open discontinuities between ~0.4 and 0.2 inches (1 to 5 mm).
Very Poor Condition	Soft gouge greater than ~0.2 inches (5 mm), or open discontinuities greater than ~0.2 inches (5 mm).

DISCONTINUITY SPACING (INCLUDES JOINTS/FRACTURES, BEDDING, AND FAULTS	
Description	**Spacing of Discontinuity**
Extremely Widely Spaced	>20 feet (>6 m)
Very Widely Spaced	~6 to 20 feet (2 to 6 m)
Widely Spaced	~2 to 6 feet (600 mm to 2 m)
Moderately Spaced	~8 inches to 2 feet (200 to 600 mm)
Closely Spaced	~2 to 8 inches (60 to 200 mm)
Very Closely Spaced	~3/4 to 2 inches (20 to 60 mm)
Extremely Closely Spaced	<3/4 inches (<20 mm)

$$CR\ (\%) = \left(\frac{Total\ Length\ of\ Core\ Recovered}{Total\ Length\ of\ Core\ Run\ Drilled}\right) * 100$$

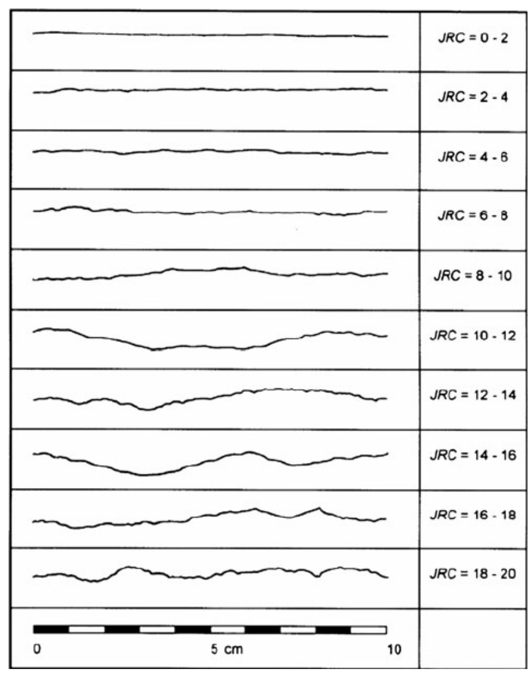
$$RQD\ (\%) = \frac{Length\ of\ Sound\ Core\ in\ pieces > 4\ inches\ (100\ mm)}{Total\ Length\ of\ Core\ Run}\ x\ 100$$

$$FF = \frac{Number\ of\ natural\ fractures}{Total\ length\ of\ core\ recovered\ (feet)}$$

GRAIN SHAPE (FOR SEDIMENTARY ROCKS)	
Description	**Characteristic**
Angular	Showing very little evidence of wear. Grain edges and corners are sharp. Secondary corners are numerous and sharp.
Subangular	Showing definite effects of wear. Grain edges and corners are slightly rounded off. Secondary corners are slightly less numerous and slightly less sharp than in angular grains.
Subrounded	Showing considerable wear. Grain edges and corners are rounded to smooth curves. Secondary corners are reduced greatly in number and highly rounded.
Rounded	Showing extreme wear. Grain edges and corners are smoothed off the broad curves. Secondary corner are few in number and rounded.
Well-rounded	Completely worn. Grain edges or corners are not present. No secondary edges or corners are present.

RELATIVE STRENGTH OF SOIL INFILLING (ISRM, 1978 & 1981)			
Grade	**Description**	**Field Identification**	**Approximate Uniaxial Compressive Strength**
S1	Very Soft	Easily penetrated several inches by fist	<3.5 psi (<25 kPa)
S2	Soft	Easily penetrated severl inches by thumb	3.5 - 7 psi (25 - 50 kPa)
S3	Firm	Can be penetrated several inches by thumb with moderate effort	7 - 14.5 psi (50 - 100 kPa)
S4	Stiff	Readily indented by thumb but penetrated only with great effort	14.5 - 36 psi (100 - 250 kPa)
S5	Very Stiff	Readily indented by thumbnail	36 - 72.5 psi (250 - 500 kPa)
S6	Hard	Indented with difficulty by thumbnail	>72 psi (>500 kPa)

JRC RANGES (ISRM, 1978 &1981)

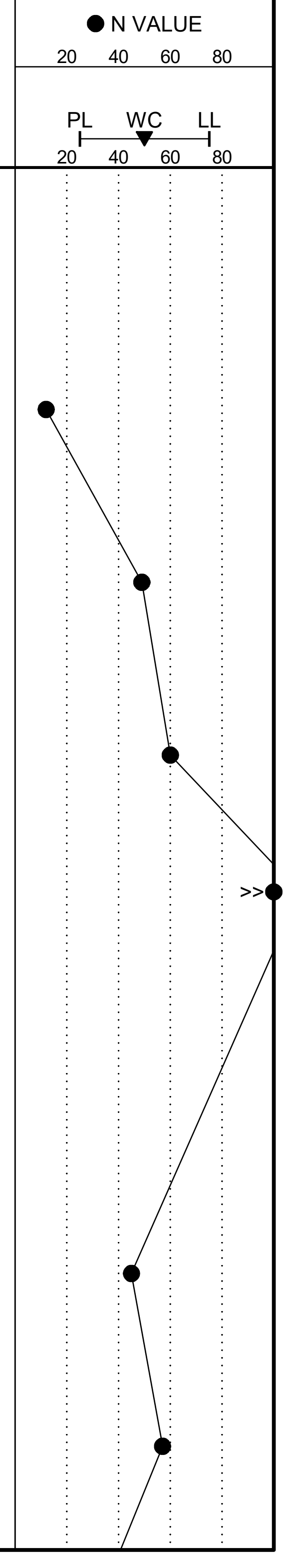


U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-02

Project Name: Pretty Rocks
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3620 ft   Datum: MSL
Groundwater Depth:
While Drilling: ---
At Completion: ---
After Drilling: --- No groundwater encountered
Date Started: 7/11/18   Date Completed: 7/17/18
Driller/Company: Tim Beckner/Geotek Alaska   Drill: CME-75
Hammer Type: 340 lbs Automatic
Logger/Company: Orion George
Weather: Rain
Notes:
VWP (S/N: 1816098); SAAV installed in 3.34" SI casing to 114'; thermistor string to 120'

Elevation (ft)	Depth (ft)	MATERIAL DESCRIPTION	Drilling Method	Sample No.	Field Blow Count (Recovery)	Test Results
		2.5 ft / El. 3617.5 ft	6.25" ID			
		Well graded SAND with gravel, medium dense, gray, dry, fine sand, angular, trace silt, cobble likely. Colluvium.		S01	4-7-5-4 (1" = 4%)	
3615	5	Very dense, some silt.		S02	5-21-28-15 (24" = 100%)	
				S03	25-30-30-23 (24" = 100%)	
3610	10	Increasing silt.		S04	17-50/6" (16" = 139%)	
				S05	50 (5" = 45%)	
3605	15	Dense, increasing gravel.		S06	20-22-23-26 (24" = 100%)	
		Very dense.		S07	17-31-26-25 (24" = 100%)	

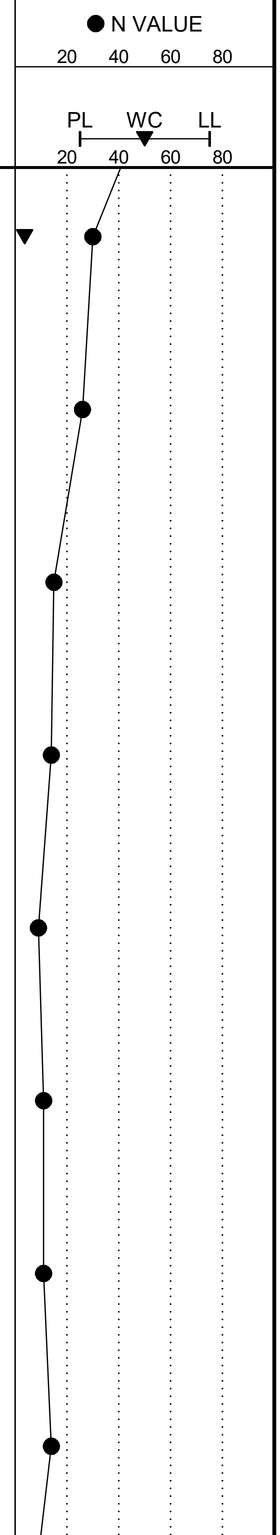


U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-02

Project Name: Pretty Rocks
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3620 ft
Datum: MSL
Groundwater Depth:
While Drilling: ---
At Completion: ---
After Drilling: --- No groundwater encountered
Date Started: 7/11/18
Date Completed: 7/17/18
Driller/Company: Tim Beckner/Geotek Alaska
Drill: CME-75
Hammer Type: 340 lbs Automatic
Logger/Company: Orion George
Weather: Rain
Notes:
VWP (S/N: 1816098); SAAV installed in 3.34" SI casing to 114'; thermistor string to 120'

Elevation (ft)	Depth (ft)	MATERIAL DESCRIPTION	Drilling Method	Type	No.	Field Blow Count (Recovery)	Test Results
		Well graded SAND with gravel, medium dense, gray, dry, fine sand, angular, trace silt, cobble likely. Colluvium. *(continued)* Medium dense, tan, moist, becoming angular, mostly rhyolite with some basalt incorporated.	6.25" ID		S08	7-17-13-11 (22" = 92%)	
		Out of rhyolite.			S09	7-15-11-11 (20" = 83%)	
3595	25	No recovery.			S10	4-9-6-6 (0" = 0%)	
		Rhyolite cobbles up to 0.7'. 28.6 ft / El. 3591.4 ft			S11	3-7-7-4 (17" = 71%)	
		Poorly graded GRAVEL with clay and sand, medium dense, brown with tan, moist, fine sand, angular, slow dilatancy, high toughness, high plasticity, cobbles likely. Landslide debris. Loose.					
3590	30	40.8° F measured			S12	3-4-5-5 (14" = 58%)	
		Medium dense, with few obsidian clasts. 39.8° F measured			S13	6-6-5-6 (16" = 67%)	
3585	35	Rhyolite boulders and cobbles likely. 46.5° F measured			S14	3-6-5-8 (17" = 71%)	
		Purple and red clasts incorporated. 43.5° F measured 40 ft / El. 3580 ft			S15	7-8-6-6 (16" = 67%)	

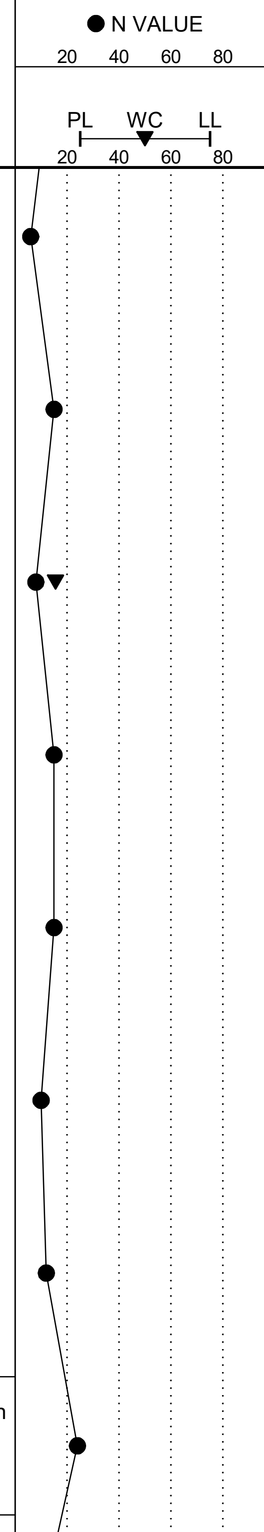


U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-02

Project Name: Pretty Rocks
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3620 ft
Datum: MSL
Groundwater Depth:
While Drilling: ---
At Completion: ---
After Drilling: --- No groundwater encountered
Date Started: 7/11/18
Date Completed: 7/17/18
Driller/Company: Tim Beckner/Geotek Alaska
Drill: CME-75
Hammer Type: 340 lbs Automatic
Logger/Company: Orion George
Weather: Rain
Notes: VWP (S/N: 1816098); SAAV installed in 3.34" SI casing to 114'; thermistor string to 120'

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Sample Type	Sample No.	Field Blow Count (Recovery)	Test Results
			Clayey SAND with gravel, loose, brown with gray and tan, wet, coarse gravel, angular, no dilatancy, high toughness, high plasticity, with obsidian clasts, cobble likely. Landslide debris. 49.5° F measured	6.25" ID		S16	2-2-4-7 (14" = 58%)	
			Medium dense, moist, boulders likley. 42.9° F measured			S17	4-8-7-5 (20" = 83%)	
3575	45		38.5° F measured			S18	2-4-4-4 (17" = 71%)	
			39.3° F measured			S19	9-7-8-7 (18" = 75%)	
3570	50		37.9° F measured			S20	2-5-10-7 (18" = 75%)	
			Loose. 42.5° F measured			S21	1-5-5-5 (16" = 67%)	
3565	55		Medium dense. 38.0° F measured			S22	3-4-8-8 (22" = 92%)	
			41.8° F measured			S23	6-8-16-10 (21" = 88%)	sample split in S23a and S23b for gradation



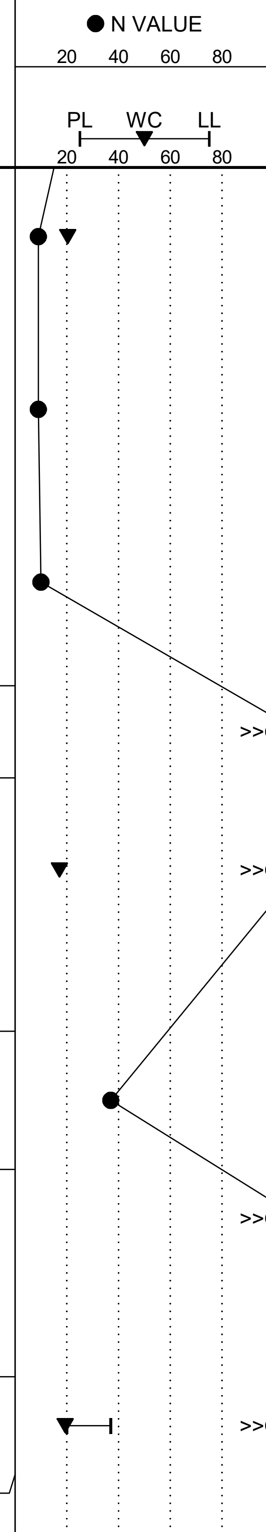
U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-02

Project Name: Pretty Rocks
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3620 ft
Datum: MSL
Groundwater Depth:
While Drilling: ---
At Completion: ---
After Drilling: --- No groundwater encountered
Date Started: 7/11/18
Date Completed: 7/17/18
Driller/Company: Tim Beckner/Geotek Alaska
Drill: CME-75
Hammer Type: 340 lbs Automatic
Logger/Company: Orion George
Weather: Rain
Notes: VWP (S/N: 1816098); SAAV installed in 3.34" SI casing to 114'; thermistor string to 120'

Drilling Method: 6.25" ID

Elevation (ft)	Depth (ft)	Material Description	Sample Type	No.	Field Blow Count (Recovery)	Test Results
		Clayey SAND with gravel, loose, brown with gray and tan, wet, coarse gravel, angular, no dilatancy, high toughness, high plasticity, with obsidian clasts, cobble likely. Landslide debris. *(continued)* Loose.	X	S24	3-4-5-6 (20" = 83%)	
		41.0° F measured	X	S25	4-5-4-5 (14" = 58%)	
3555	65	65 ft / El. 3555 ft				
		Poorly graded GRAVEL with clay and sand, loose, light brown, coarse gravel, angular, no dilatancy, high toughness, high plasticity. 39.7° F measured	X	S26	2-5-5-4 (12" = 50%)	
		Very dense. Beginning at 67.8', massive interstitial irregularly oriented ice inclusions observed, ~70% visible ice, hard, and clear to colorless. 31.5° F measured	X	S27	12-19-50/4" (21" = 131%)	68.0' to 69.1' separated & frozen
3550	70	At 70' no ice observed	X	S28	50/4" (4" = 100%)	
		72.5 ft / El. 3547.5 ft				
		Clayey SAND with gravel (SC), dense, brown, coarse sand, angular, no dilatancy, high toughness, high plasticity, ~60% visible ice.. 29.7° F measured	X	S29	7-13-24-30 (18" = 75%)	73.7' to 74.0' separated & frozen
3545	75	~40% visible ice.. 30.5° F measured	X	S30	50/5" (5" = 100%)	
		30.1° F measured	X	S31	16-22-50/5" (21" = 124%)	Fines = 15% SG = 2.53 77.5' to 78.7' separated & frozen



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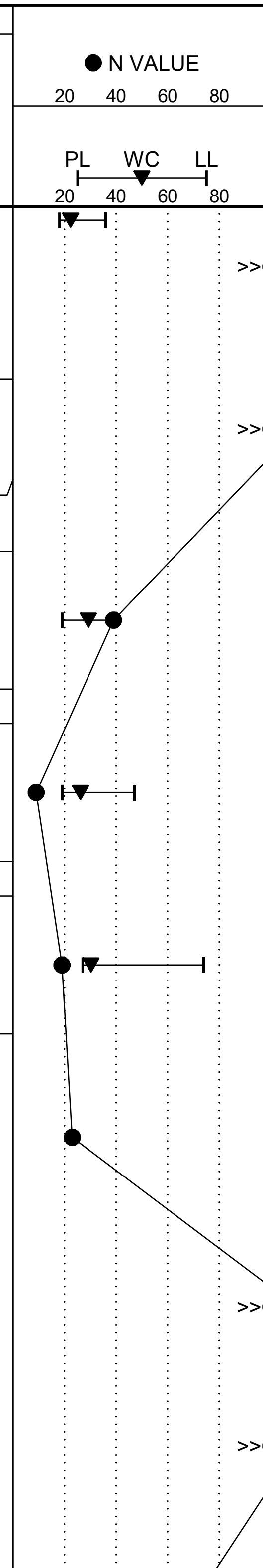
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-02

Project Name: Pretty Rocks
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3620 ft
Datum: MSL
Groundwater Depth:
While Drilling: ---
At Completion: ---
After Drilling: --- No groundwater encountered
Date Started: 7/11/18
Date Completed: 7/17/18
Driller/Company: Tim Beckner/Geotek Alaska
Drill: CME-75
Hammer Type: 340 lbs Automatic
Logger/Company: Orion George
Weather: Rain
Notes: VWP (S/N: 1816098); SAAV installed in 3.34" SI casing to 114'; thermistor string to 120'

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample Type	No.	Field Blow Count (Recovery)	Test Results
		80.2 ft / El. 3539.8 ft Clayey GRAVEL with sand (GC), very dense, brown, fine gravel, angular, massive interstitial irregularly and stratified oriented ice inclusions, ~70% visible ice. 29.9° F measured	6.25" ID	X	S32	28-26-36-50/3" (22" = 105%)	Fines = 17% SG = 2.60
		~45% visible ice, 83.5' to 84.0' of sample melted: ~30% supernatant water. 30.4° F measured	6.25" ID	X	S33	22-48-50/6" (19" = 109%)	83.5' to 84.0' melted with ~30% supernatant water
3535	85	85 ft / El. 3535 ft Clayey SAND with gravel (SC), dense, brown, coarse sand, angular, ~35% visible ice. 29.9° F measured	6.25" ID	X	S34	12-21-18-11 (24" = 100%)	Fines = 15% SG = 2.61 85.9' to 87.0' separated & frozen
		88.4 ft / El. 3531.6 ft Fat CLAY with sand, stiff, gray to light olive gray, fine sand, no dilatancy, high toughness, high plasticity, frozen with no visible ice, well bonded, no excess ice. VOLCANIC ASH. 29.9° F measured	6.25" ID	X	S35	3-3-6-6 (18" = 75%)	88.4' to 89.5' separated & frozen
3530	90	90 ft / El. 3530 ft Clayey SAND (SC), medium dense, blue gray, dry, fine sand, not frozen. 35.9° F measured	6.25" ID	X	S36	5-7-12-23 (24" = 100%)	Fines = 38% SG = 2.62
		Small white specs < 1 mm appear to be relict bedrock texture altered to clay. 39.4° F measured	tri-cone, compressed air	X	S37	5-10-13-25 (26" = 108%)	
3525	95	Steeply dipping relict structure observed, zones of less clayey alteration. 37.8° F measured	tri-cone, compressed air	X	S38	6-11-18-50/5" (24" = 104%)	
		96.8 ft / El. 3523.2 ft Clayey SAND with gravel, very dense, light gray, dry, medium sand, angular, no dilatancy, high toughness, high plasticity, VOLCANIC ASH. 38.1° F measured	tri-cone, compressed air	X	S39	23-50/6" (10" = 87%)	



U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-02

Project Name: Pretty Rocks

Project Location: Denali National Park and Preserve, Alaska

Surface Elevation: 3620 ft

Datum: MSL

Groundwater Depth:

While Drilling: ---

At Completion: ---

After Drilling: --- No groundwater encountered

Date Started: 7/11/18

Date Completed: 7/17/18

Driller/Company: Tim Beckner/Geotek Alaska

Drill: CME-75

Hammer Type: 340 lbs Automatic

Logger/Company: Orion George

Weather: Rain

Notes:
VWP (S/N: 1816098); SAAV installed in 3.34" SI casing to 114'; thermistor string to 120'

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample No.	Field Blow Count (Recovery)	Test Results	N Value
		Clayey SAND with gravel, very dense, light gray, dry, medium sand, angular, no dilatancy, high toughness, high plasticity, VOLCANIC ASH. *(continued)* 39.3° F measured	tri-cone, compressed air	S40	13-20-37-44 (24" = 100%)		
		103.1 ft / El. 3516.9 ft					
		Sandy fat CLAY with gravel, very stiff, gray, dry, fine gravel, angular, no dilatancy, high toughness, high plasticity, gravel clasts are vesicular basalt. VOLCANIC ASH. 40.1° F measured		S41	15-18-24-28 (24" = 100%)		
3515	105	105 ft / El. 3515 ft					
		Fat CLAY with sand, very stiff, gray to olive gray, dry, medium sand, no dilatancy, high toughness, high plasticity, stratified, bedding observable. VOLCANIC ASH.		S42	6-10-22-31 (26" = 108%)		
		Moist.		S43	9-18-21-50/6" (25" = 106%)	stored in core box	>>
				S44	(6" = 100%)		
3510	110			S45	13-21-32-50/5" (25" = 109%)	stored in core box	>>
		112.5 ft / El. 3507.5 ft					
		Sandy fat CLAY with gravel, very stiff, gray, dry, fine gravel, no dilatancy, high toughness, high plasticity, VOLCANIC ASH.		S46	16-23-40-50/3" (25" = 119%)	stored in core box	>>
3505	115			S47	11-21-31-50/5" (25" = 109%)	stored in core box	>>

N VALUE scale: 20 40 60 80; PL WC LL scale: 20 40 60 80

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-02

Project Name: Pretty Rocks
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3620 ft
Datum: MSL
Groundwater Depth:
Date Started: 7/11/18
Date Completed: 7/17/18
While Drilling: ---
Driller/Company: Tim Beckner/Geotek Alaska
Drill: CME-75
At Completion: ---
Hammer Type: 340 lbs Automatic
After Drilling: --- No groundwater encountered
Logger/Company: Orion George
Weather: Rain
Notes:
VWP (S/N: 1816098); SAAV installed in 3.34" SI casing to 114'; thermistor string to 120'

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Sample Type	Sample No.	Field Blow Count (Recovery)	Test Results	N VALUE (20 40 60 80) / PL WC LL (20 40 60 80)
			Sandy fat CLAY with gravel, very stiff, gray, dry, fine gravel, no dilatancy, high toughness, high plasticity, VOLCANIC ASH. *(continued)* Dark gray, stratified, bedding observed at 75° from horizontal.	tri-cone, compressed air		S48	7-13-19-44 (25" = 104%)	stored in core box	
3495	125					S49	5-8-20-35 (25" = 104%)	stored in core box	
3490	130		Stiff, moist.			S50	3-5-7-14 (25" = 104%)		
3485	135		Very stiff, dry.			S51	12-50/1" (15" = 214%)		>>

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-02

Project Name: Pretty Rocks
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3620 ft
Datum: MSL
Groundwater Depth:
While Drilling: ---
At Completion: ---
After Drilling: --- No groundwater encountered
Date Started: 7/11/18
Date Completed: 7/17/18
Driller/Company: Tim Beckner/Geotek Alaska
Drill: CME-75
Hammer Type: 340 lbs Automatic
Logger/Company: Orion George
Weather: Rain
Notes:
VWP (S/N: 1816098); SAAV installed in 3.34" SI casing to 114'; thermistor string to 120'

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	SAMPLE Type	SAMPLE No.	SAMPLE Field Blow Count (Recovery)	SAMPLE Test Results	● N VALUE (20 40 60 80); PL WC LL (20 40 60 80)
			140.3 ft / El. 3479.7 ft			S52	50/4" (4" = 100%)		>>
			Bottom of borehole at 140.3 ft.						

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FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

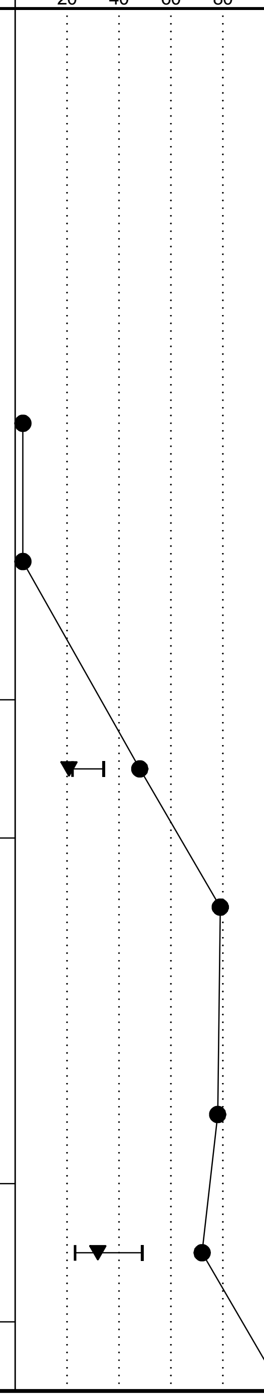
BORING LOG PR18-03

Project Name: Pretty Rocks
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3581 ft
Datum: MSL
Groundwater Depth:
While Drilling: ---
At Completion: ---
After Drilling: --- No groundwater encountered
Date Started: 7/27/18
Date Completed: 7/30/18
Driller/Company: Travis Drewery/Geotek Alaska
Drill: Geoprobe 6620 DT
Hammer Type: 140 lbs Automatic
Logger/Company: Brian Collins

Notes:
VWP (S/N: 1814519); SAAV installed in 3.34" SI casing to 95';
thermistor string to 96'

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results
3580			6.25" ID			
3578.5	2.5	2.5 ft / El. 3578.5 ft				
		COBBLES, Clayey SAND, brown and white, moist, angular, mostly cobbles with boulders up to 3', mostly rhyolite clasts. Colluvium.				
	5	Very loose.				
3575				S1	2-1-2-3 (9" = 38%)	
				S2	2-3-0-0 (2" = 8%)	
3572	9	9 ft / El. 3572 ft				
	10	Clayey SAND with gravel (SC), dense, brown, moist, medium sand, angular, soil unfrozen, but 1" layers of ice and individual ice inclusions, 32.5° measured.				
3570				S3	9-23-25-42 (24" = 100%)	Fines = 13% SG = 2.55
		Very dense, 37° F measured.				
				S4	27-45-34-37 (24" = 100%)	
	15	35° F measured.				
3565				S5	35-42-36-50 (24" = 100%)	
		Clayey SAND with gravel (SC), dense, brown, moist, medium sand, angular, occasional cobbles and boulders, soils frozen, poorly bonded with individual ice inclusions, ~5% visible ice, 31° F measured.		S6	36-50-22-15 (24" = 100%)	Fines = 22% SG = 2.51
3561.5	19.5	19.5 ft / El. 3561.5 ft				

● N VALUE (20, 40, 60, 80)
PL — WC — LL (20, 40, 60, 80)
RQD (%) / Recovery (%) (20, 40, 60, 80)



U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-03

Project Name: Pretty Rocks

Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3581 ft
Datum: MSL
Groundwater Depth:
Date Started: 7/27/18
Date Completed: 7/30/18
While Drilling: ---
Driller/Company: Travis Drewery/Geotek Alaska
Drill: Geoprobe 6620 DT
At Completion: ---
Hammer Type: 140 lbs Automatic
After Drilling: --- No groundwater encountered
Logger/Company: Brian Collins
Notes:
VWP (S/N: 1814519); SAAV installed in 3.34" SI casing to 95'; thermistor string to 96'

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	N Value
3560		Silty GRAVEL with sand, very dense, brown, wet, medium sand, angular, occasional cobbles and boulders, soil unfrozen, 37° F measured. 22.5 ft / El. 3558.5 ft	6.25" ID	S7	18-50/5" (11" = 100%)		>>
		Clayey SAND with gravel, dense, brown, moist, medium sand, angular, occasional cobbles and boulders, soil unfrozen, 32.5° F measured.		S8	17-21-22-30 (24" = 100%)		
3555	25	Very dense, soils with poorly bonded frozen layers, 32.5° F measured. 26.5 ft / El. 3554.5 ft		S9	50/6" (6" = 100%)		
		Clayey GRAVEL with sand, very dense, brown, moist, medium sand, angular, occasional cobbles and boulders, 38° F measured. driller comments boulder 27.5' - 29.5' 29.5 ft / El. 3551.5 ft		S10	45-50/6" (6" = 100%)		>>
3550	30	Clayey GRAVEL, very dense, brown, moist, medium sand, angular, soft, colorless, cloudy ICE 30.0' - 30.25', soils unfrozen 30.25' to 30.75', soils frozen with individual ice inclusions below 30.75', ~ 20% visible ice, 32° F to 38° F measured.		S11	28-50/5" (11" = 100%)		>>
		37° F measured, driller remarks softer 32.0' - 35.0'. 33 ft / El. 3548 ft		S12	50/5" (3" = 60%)		>>
3545	35	Very dense, ICE without soil inclusions, soft, colorless, cloudy, horizontal layers, 31° F measured. 36 ft / El. 3545 ft		S13	27-27-25-24 (24" = 100%)		
		Clayey GRAVEL with sand, very dense, brown, medium sand, angular, occasional cobbles and boulders, soils frozen with ice inclusions ~30% visible ice, 31° F measured. 37.5 ft / El. 3543.5 ft					
		Very dense, ICE without soil inclusions, soft, white, 31° F measured. ICE 39.5 ft / El. 3541.5 ft		S14	19-38-23-40 (24" = 100%)		

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-03

Project Name: Pretty Rocks
Sheet: 3 of 6
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3581 ft
Datum: MSL
Groundwater Depth:
Date Started: 7/27/18
Date Completed: 7/30/18
While Drilling: ---
Driller/Company: Travis Drewery/Geotek Alaska
Drill Geoprobe 6620 DT
At Completion: ---
Hammer Type: 140 lbs Automatic
After Drilling: --- No groundwater encountered
Logger/Company: Brian Collins
Notes:
VWP (S/N: 1814519); SAAV installed in 3.34" SI casing to 95'; thermistor string to 96'

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	N Value
3540		Clayey SAND with gravel (SC), very dense, brown, occasional cobbles and boulders, frozen with occasional ice inclusions ~10% ice visible, 30.5° F measured.	6.25" ID	S15	45-44-50/5" (17" = 100%)	Fines = 24% SG = 2.76	>>
		Frozen soils with ice inclusions, ~50% visible ice, 30° F measured.		S16	39-50/3" (9" = 100%)		>>
	45	31° F measured.		S17	50/6" (6" = 100%)		
3535		Layers of unfrozen and frozen soils with ~30% visible ice inclusions, 32° - 36° F measured.		S18	31-50/6" (12" = 100%)		
	50	ICE, soft, clear to cloudy 50.0' - 50.5', 31° F measured.		S19	49-29-50/5" (17" = 100%)		>>
3530		Frozen soils with ice inclusions, ~30% visible ice, 31.5° F measured, driller comments very soft drilling 52.0' - 55.0'.		S20	34-50/3" (8" = 89%)		>>
	55	Clayey SAND with gravel (SC), dense, 37° F measured.					
3525		56 ft / El. 3525 ft Elastic SILT, very stiff, light blue gray, moist, medium to high plasticity, disrupted, 0.2' of wet angular gravel clasts at 56.0'.		S21	6-14-24-12 (24" = 100%)	Fines = 24% SG = 2.74	
		57 ft / El. 3524 ft Clayey SAND (SC), blue green, 38° F measured. TUFF, blue green, completely weathered. RCT 2 min. RCT 30 min.	HQ, compressed air	R1 S22	Rec = 55% RQD = 0% 8-13-14-21 (24" = 100%)	Fines = 40% SG = 2.79	

BORING LOG PR18-03

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

Project Name: Pretty Rocks
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3581 ft
Datum: MSL
Groundwater Depth:
While Drilling: ---
At Completion: ---
After Drilling: --- No groundwater encountered
Date Started: 7/27/18
Date Completed: 7/30/18
Driller/Company: Travis Drewery/Geotek Alaska
Drill: Geoprobe 6620 DT
Hammer Type: 140 lbs Automatic
Logger/Company: Brian Collins

Notes:
VWP (S/N: 1814519); SAAV installed in 3.34" SI casing to 95'; thermistor string to 96'

Elevation (ft)	Depth (ft)	MATERIAL DESCRIPTION	Drilling Method	Sample No.	Core Rec., RQD	Test Results
3520		Clayey SAND (SC), blue green, 38° F measured. TUFF, blue green, completely weathered. RCT 2 min. *(continued)*	HQ, compressed air	R2	Rec = 27% RQD = 0%	
3518	63	63 ft / El. 3518 ft RHYOLITE, bluish grey, fine grained grained, moderately weathered, strong rock (R4). Discontinuities are very closely spaced to extremely closely spaced and in poor condition, range from JRC 4-6 degrees from assumed horizontal, continuous chatter while drilling, RCT 50 min.	HQ, compressed air	R3	Rec = 50% RQD = 0%	RCT 50 min
3515	65					
		Driller remarks "like drilling on marbles with soft layers", RCT 21 min.	HQ, compressed air	R4	Rec = 10% RQD = 0%	
3510	70					
3508	73	73 ft / El. 3508 ft RHYOLITE, grey, medium grained grained, moderately weathered to completely weathered, weak rock (R2). Discontinuities are in very poor condition, range from 40° - 50°, JRC 0-4 degrees from assumed horizontal, clay infill, continuous chatter while drilling, RCT 25 min.	HQ, compressed air	R5	Rec = 50% RQD = 10%	
3505	75					
		RCT 19 min.				

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-03

Project Name: Pretty Rocks
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3581 ft
Datum: MSL
Groundwater Depth:
While Drilling: ---
At Completion: ---
After Drilling: --- No groundwater encountered
Date Started: 7/27/18
Date Completed: 7/30/18
Driller/Company: Travis Drewery/Geotek Alaska
Drill: Geoprobe 6620 DT
Hammer Type: 140 lbs Automatic
Logger/Company: Brian Collins

Notes:
VWP (S/N: 1814519); SAAV installed in 3.34" SI casing to 95'; thermistor string to 96'

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results
3500		RHYOLITE, grey, medium grained grained, moderately weathered to completely weathered, weak rock (R2). Discontinuities are in very poor condition, range from 40° - 50°, JRC 0-4 degrees from assumed horizontal, clay infill, continuous chatter while drilling, RCT 25 min. *(continued)*	HQ, compressed air	R6	Rec = 45% RQD = 0%	
	85	RCT 19 min.	HQ, compressed air	R7	Rec = 65% RQD = 0%	
3495						
	90	RCT 27 min.	HQ, compressed air	R8	Rec = 50% RQD = 0%	
3490						
		93 ft / El. 3488 ft				
	95	TUFF. RCT 25 min.	HQ, compressed air	R9	Rec = 3% RQD = 0%	
3485						
		Grey, fine grained grained, highly weathered, very weak rock (R1). Discontinuities are very closely spaced, RCT 13 min.	HQ, compressed air			

N VALUE: 20 40 60 80; PL WC LL: 20 40 60 80; RQD (%) / Recovery (%): 20 40 60 80

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-03

Project Name: Pretty Rocks
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3581 ft
Datum: MSL
Groundwater Depth:
While Drilling: ---
At Completion: ---
After Drilling: --- No groundwater encountered
Date Started: 7/27/18
Date Completed: 7/30/18
Driller/Company: Travis Drewery/Geotek Alaska
Drill: Geoprobe 6620 DT
Hammer Type: 140 lbs Automatic
Logger/Company: Brian Collins

Notes:
VWP (S/N: 1814519); SAAV installed in 3.34" SI casing to 95';
thermistor string to 96'

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	N VALUE / PL WC LL / RQD (%) Recovery (%)
3480			TUFF. RCT 25 min. *(continued)*	HQ, compressed air		R10	Rec = 45% RQD = 0%		
			RCT 20 min.			R11	Rec = 40% RQD = 0%		
3475	105		108 ft / El. 3473 ft						

Bottom of borehole at 108 ft.

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-04

Project Name: Pretty Rocks
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3493 ft
Datum: MSL
Groundwater Depth:
Date Started: 8/21/18
Date Completed: 8/25/18
∇ While Drilling: 14.5 ft / Elev 3478.5 ft
Driller/Company: Glen Rawson/Geotek Alaska
Drill: Geoprobe 6620 DT
At Completion: ---
Hammer Type: 140 lbs Automatic
After Drilling: ---
Logger/Company: Nick Farny
Weather: Partly cloudy
Notes:
VWP (SN: 1814519); thermistor string to 48'

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	N VALUE (20 40 60 80); PL WC LL (20 40 60 80); RQD (%) / Recovery (%) (20 40 60 80)
			COBBLES AND BOULDERS, angular, rhyolite and basalt fragments. Fill created by drillers to construct drilling pad. 2.5 ft / El. 3490.5 ft	6.25" ID					
3490			COBBLES AND BOULDERS in a Poorly graded GRAVEL with clay and sand matrix, matrix is loose, brown, moist, coarse gravel, loose, medium sand, subangular to angular, clasts up to 1', 54° F measured.						
	5					S1	9-9-1-1 (8" = 33%)		
			7.5 ft / El. 3485.5 ft						
3485			COBBLES AND BOULDERS in a Clayey GRAVEL with sand matrix, matrix is very dense, brown, wet, angular to subangular, fine to coarse gravel, medium to coarse sand, 33° F measured.			S2	12-50/3" (6" = 67%)		>>
			10 ft / El. 3483 ft						
	10		COBBLES AND BOULDERS in a Silty GRAVEL with sand matrix, matrix is very dense, wet to moist, white to brown, subangular to angular, medium to coarse sand, fine to coarse gravel. Frozen, Vs, ice crystals visible, lenses horizontal up to 1/8" thick, low ice saturation, spaced 1/4", milky, 32° F measured. 12.5 ft / El. 3480.5 ft			S3	12-50/2" (6" = 75%)		>>
3480			ICE, hard, gray, cloudy, inclusions of silty GRAVEL with cobbles, soil is very dense, brown, wet, angular, coarse to fine gravel, medium to coarse sand, 31.5° F measured. ∇ 15 ft / El. 3478 ft			S4	50/6" (6" = 100%)		
	15		Silty GRAVEL with sand, brown, wet, cobbles, and boulders, angular to subangular, medium sand, fine to coarse gravel, very dense, 35° F measured. 16.5 ft / El. 3476.5 ft			S5	50/3" (3" = 100%)		>>
3475			Poorly graded GRAVEL with silt and sand, brown, wet, angular to subangular, coarse to fine gravel, medium sand, very dense. Frozen, Nf, low saturation, 32° F measured.			S6	50/4" (4" = 100%)		>>

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-04

Project Name: Pretty Rocks
Sheet: 2 of 6
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3493 ft
Datum: MSL
Groundwater Depth:
Date Started: 8/21/18
Date Completed: 8/25/18
While Drilling: 14.5 ft / Elev 3478.5 ft
Driller/Company: Glen Rawson/Geotek Alaska
Drill: Geoprobe 6620 DT
At Completion: ---
Hammer Type: 140 lbs Automatic
After Drilling: ---
Logger/Company: Nick Farny
Notes:
Weather: Partly cloudy
VWP (SN: 1814519); thermistor string to 48'

Elevation (ft)	Depth (ft)	MATERIAL DESCRIPTION	Drilling Method	Sample Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	N VALUE
		Poorly graded GRAVEL with silt and sand, brown, wet, angular to subangular, coarse to fine gravel, medium sand, very dense. Frozen, Nf, low saturation, 32° F measured. *(continued)* 31.5° F measured at 20'	6.25" ID		S7	50/3" (3" = 100%)		>>
		22.5 ft / El. 3470.5 ft						
3470		Poorly graded GRAVEL with silt and sand, brown, wet, cobbles, subangular to angular, coarse to fine gravel, medium sand, very dense, 38° F measured.			S8	50/5" (5" = 100%)		>>
		25 ft / El. 3468 ft						
	25	ICE, hard, gray, cloudy, inclusions of silty GRAVEL with sand, wet, very dense, brown, fine to coarse gravel, medium sand, subangular to angular, 31.5° F measured.			S9	40-50/3" (6" = 67%)		>>
3465								
	30				S10	50/3" (3" = 100%)		>>
3460		31.5 ° measured.			S11	40-50/4" (6" = 60%)		>>
	35				S12	50/6" (6" = 100%)		>>
		37.5 ft / El. 3455.5 ft						
3455		ICE, hard, cloudy, gray, inclusions of silty SAND with gravel, brown, very dense, wet, fine gravel, medium to fine sand, angular to subangular, 31.5 ° measured.			S13	20-33-50/3" (15" = 100%)		>>

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-04

Project Name: Pretty Rocks
Sheet: 3 of 6
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3493 ft
Datum: MSL
Groundwater Depth:
Date Started: 8/21/18
Date Completed: 8/25/18
While Drilling: 14.5 ft / Elev 3478.5 ft
Driller/Company: Glen Rawson/Geotek Alaska
Drill: Geoprobe 6620 DT
At Completion: ---
Hammer Type: 140 lbs Automatic
After Drilling: ---
Logger/Company: Nick Farny
Notes:
Weather: Partly cloudy
VWP (SN: 1814519); thermistor string to 48'

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	N VALUE
			ICE, hard, cloudy, gray, inclusions of silty SAND with gravel, brown, very dense, wet, fine gravel, medium to fine sand, angular to subangular, 31.5 ° measured. *(continued)*	6.25" ID		S14	50/6" (6" = 100%)		
3450									
	45					S15	17-30-33-47 (18" = 75%)		
3445						S16	25-50/6" (12" = 100%)		
			49 ft / El. 3444 ft						
			VOID from 49' to 50'.						
			50 ft / El. 3443 ft						
	50		RHYOLITE, highly weathered to completely weathered, extremely weak rock (R0). gray to brown, fine grained, residual soil is lean CLAY with gravel and sand, hard, moist to wet, low plasticity to medium plasticity, fine to coarse gravel.			S17	17-27-50/6" (18" = 100%)		
3440									
	55		White, moderately weathered, weak rock (R2) to medium strong rock (R3).			S18	50/1" (1" = 100%)		>>
3435									

N VALUE: 20 40 60 80; PL WC LL: 20 40 60 80; RQD (%) / Recovery (%): 20 40 60 80

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-04

Project Name: Pretty Rocks
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3493 ft
Datum: MSL
Groundwater Depth:
Date Started: 8/21/18
Date Completed: 8/25/18
While Drilling: 14.5 ft / Elev 3478.5 ft
Driller/Company: Glen Rawson/Geotek Alaska
Drill: Geoprobe 6620 DT
At Completion: ---
Hammer Type: 140 lbs Automatic
After Drilling: ---
Logger/Company: Nick Farny
Notes:
Weather: Partly cloudy
VWP (SN: 1814519); thermistor string to 48'

Elevation (ft)	Depth (ft)	MATERIAL DESCRIPTION	Drilling Method	Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	N VALUE / RQD (%) / Recovery (%)
		RHYOLITE, highly weathered to completely weathered, extremely weak rock (R0). gray to brown, fine grained, residual soil is lean CLAY with gravel and sand, hard, moist to wet, low plasticity to medium plasticity, fine to coarse gravel. *(continued)*	6.25" ID		S19	50/2" (3" = 150%)		>>
3430								
	65				S20	50/3" (2" = 67%)		>>
3425		Extremely weak rock (R0) to medium strong rock (R3). brown to gray to white, highly weathered, residual soil is clayey GRAVEL with cobbles, moist, subrounded to subangular, coarse gravel, RCT=13 min. 54 sec., discontinuities are extremely closely spaced to very closely spaced and in poor condition, clay infilling, orientation unknown, structure lost, 54° F measured.	HQ, compressed air					
	70				R1	Rec = 18% RQD = 0% FF = 10		
3420					R2	Rec = 17% RQD = 0% FF = 10		
	75	75 ft / El. 3418 ft						
		ASH TUFF, gray, highly weathered to moderately weathered. RCT= 29 min. 46 sec. Discontinuities are very closely spaced to closely spaced and are in very poor condition, Discontinuities are oriented at 0 to 45° from assumed horizontal, residual soil is fat CLAY, hard, high plasticity to medium plasticity.			R3	Rec = 100% RQD = 47% FF = 3		
3415		RCT= 30 min. 36 sec.						

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-04

Project Name: Pretty Rocks
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3493 ft
Datum: MSL
Groundwater Depth:
Date Started: 8/21/18
Date Completed: 8/25/18
While Drilling: 14.5 ft / Elev 3478.5 ft
Driller/Company: Glen Rawson/Geotek Alaska
Drill: Geoprobe 6620 DT
At Completion: ---
Hammer Type: 140 lbs Automatic
After Drilling: ---
Logger/Company: Nick Farny
Notes:
Weather: Partly cloudy
VWP (SN: 1814519); thermistor string to 48'

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample No.	Core Rec., RQD, and Frac. Freq.	Test Results
		ASH TUFF, gray, highly weathered to moderately weathered. RCT= 29 min. 46 sec. Discontinuities are very closely spaced to closely spaced and are in very poor condition, Discontinuities are oriented at 0 to 45° from assumed horizontal, residual soil is fat CLAY, hard, high plasticity to medium plasticity. *(continued)* Weak rock (R2) to medium strong rock (R3). no discontinuities.	HQ, compressed air	R4	Rec = 100%, RQD = 100%, FF = 0	
3410	83	83 ft / El. 3410 ft				
		BASALT, brown, fine grained grained, highly weathered, very weak rock (R1) to weak rock (R2). Residual soil is fat CLAY with gravel, moist, high plasicity to low plasticity. RCT= 24 min. 56 sec.		R5	Rec = 100%, RQD = 83%, FF = 1.3	
	85	85 ft / El. 3408 ft				
		Moderately weathered. dark gray, fine to medium grained, medium strong rock (R3). RCT=21 min. 40 sec. Discontinuities are oriented at 0 to 45° from assumed horizontal, in poor to fair condition, very closely spaced to closely spaced, iron oxide staining.		R6	Rec = 83%, RQD = 0%, FF = 10	
3405		Dark gray brown, highly weathered to moderately weathered, medium strong rock (R3) to weak rock (R2). Discontinuities are very closely spaced to closely spaced, fair to poor condition, oriented at 0 to 45° from assumed horizontal, iron oxide stains, residual soil is clayey SAND and broken rock infill in discontinuities. RCT=32 min. 15 sec.		R7	Rec = 100%, RQD = 21%, FF = 3	
	90	Lean CLAY with sand infilling discontinuities, discontinuities are in poor to very poor condition. RCT=27 min. 18 sec.		R8	Rec = 100%, RQD = 28%, FF = 3.3	
3400		Structure lost from 93' to 94', extremely closely spaced discontinuities. RCT=31 min. 29 sec. Below 94', very closely spaced to closely spaced discontinuities.		R9	Rec = 100%, RQD = 40%, FF = 10	
	95	RCT= 21 min. 8 sec.		R10	Rec = 100%, RQD = 33%, FF = 4	
3395		Completely weathered to highly weathered. discontinuities are very closely spaced and in very poor to poor condition, residual soil is Clayey GRAVEL with sand, brown, moist, fine to coarse gravel, medium sand. RCT= 33 min. 2 sec..		R11	Rec = 100%, RQD = 0%, FF = 10	

N VALUE: 20 40 60 80; PL WC LL: 20 40 60 80; RQD (%) / Recovery (%): 20 40 60 80

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-04

Project Name: Pretty Rocks
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3493 ft
Datum: MSL
Groundwater Depth:
While Drilling: 14.5 ft / Elev 3478.5 ft
At Completion: ---
After Drilling: ---
Date Started: 8/21/18
Date Completed: 8/25/18
Driller/Company: Glen Rawson/Geotek Alaska
Drill: Geoprobe 6620 DT
Hammer Type: 140 lbs Automatic
Logger/Company: Nick Farny
Weather: Partly cloudy
Notes:
VWP (SN: 1814519); thermistor string to 48'

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample No.	Core Rec., RQD, and Frac. Freq.
		Moderately weathered. dark gray, fine to medium grained, medium strong rock (R3). RCT=21 min. 40 sec. Discontinuities are oriented at 0 to 45° from assumed horizontal, in poor to fair condition, very closely spaced to closely spaced, iron oxide staining. *(continued)*	HQ, compressed air	R12	Rec = 100% RQD = 50% FF = 1.75
3390		Moderately weathered, medium strong rock (R3). Discontinuities are very closely spaced to closely spaced and are in fine to good condition, oriented at 0 to 80° from assumed horizontal, iron oxide staining. RCT= 16 min. 23 sec. Discontinuities are extremely closely spaced, discontinuities from 105.3-106.7', some discontinuities infilled with quartz, structure lost. RCT= 48 min. 43 sec.		R13	Rec = 87% RQD = 23% FF = 2
	105				
3385		Gray dark gray, moderately weathered to slightly weathered, medium strong rock (R3). Discontinuities are moderately spaced to very closely spaced, oriented at 20-45° from assumed horizontal, and in good to fair condition, medium to fine grained. RCT= 48 min. 10 sec.		R14	Rec = 100% RQD = 92% FF = 0.8
	110				
3380		115.3 ft / El. 3377.7 ft		R15	Rec = 87% RQD = 33% FF = 2
	115	ASH TUFF with BASALT interbeds, bluish gray, highly weathered to completely weathered, very weak rock (R1) to weak rock (R2). Discontinuities are closely to very closely spaced, are in poor condition, and are oriented at 45 to 70° from assumed horizontal, RCT= 43 min. 52 sec.			
3375		RCT= 18 min. 44 sec. 120 ft / El. 3373 ft		R16	Rec = 100% RQD = 92% FF = 1

Bottom of borehole at 120 ft.

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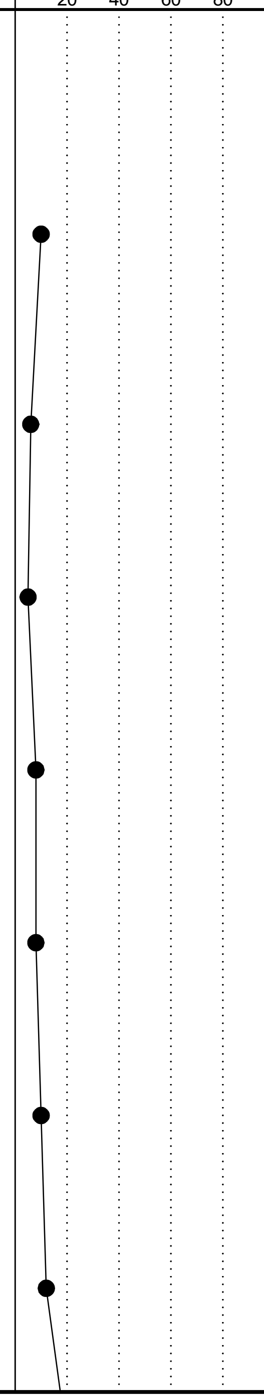
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-05

Project Name:	Pretty Rocks		
Project Location:	Denali National Park and Preserve, Alaska	Surface Elevation:	3448 ft
Datum:	MSL		
Groundwater Depth:		Date Started:	8/3/18
Date Completed:	8/12/18		
While Drilling:	---	Driller/Company:	Glen Rawson/Geotek Alaska
Drill	Geoprobe 6620 DT		
At Completion:	---	Hammer Type:	140 lbs Automatic
After Drilling:	--- No groundwater encountered	Logger/Company:	Orion George
Notes:	VWP (S/N: 1816099); thermistor string to 48'	Weather:	Overcast

Elevation (ft)	Depth (ft)	MATERIAL DESCRIPTION	Drilling Method	Sample No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results
3445		Poorly graded GRAVEL with silt and sand, loose, light tan and brown with purple, moist, medium sand, angular, some clay, boulders and cobbles.	6.25" ID	S01	5-6-4 (9" = 50%)	
	5	Poorly graded SAND with clay and gravel, loose, light tan brown, moist, medium sand, angular, low toughness, medium plasticity, boulders and cobbles likely. Dark brown. 49.4° F measured		S02	5-4-2-2 (11" = 46%)	
3440		Very loose, some perlitic obsidian and basalt, less clay.		S03	1-2-3-4 (14" = 58%)	
	10	Loose, increased gravel (~40%). 41.9° F measured		S04	1-4-4-6 (9" = 38%)	
		12.5 ft / El. 3435.5 ft				
3435		Clayey SAND with gravel, loose, brown, moist, medium sand, angular, no dilatancy, medium toughness, medium plasticity, basalt and rhyolite clasts, cobbles likely.		S05	2-4-4-7 (11" = 46%)	
	15	15 ft / El. 3433 ft				
		Clayey GRAVEL with sand, loose, brown, moist, fine gravel, angular, no dilatancy, medium toughness, medium plasticity, with cobbles, ~30% sand. 40.4° F measured		S06	6-4-6-7 (11" = 46%)	
3430		Medium dense, wet, ~60% gravel and ~15% sand. 43.8° F measured		S07	1-5-7-10 (9" = 38%)	

● N VALUE (20 40 60 80); PL WC LL (20 40 60 80); RQD (%) / Recovery (%) (20 40 60 80)



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FEDERAL HIGHWAY ADMINISTRATION
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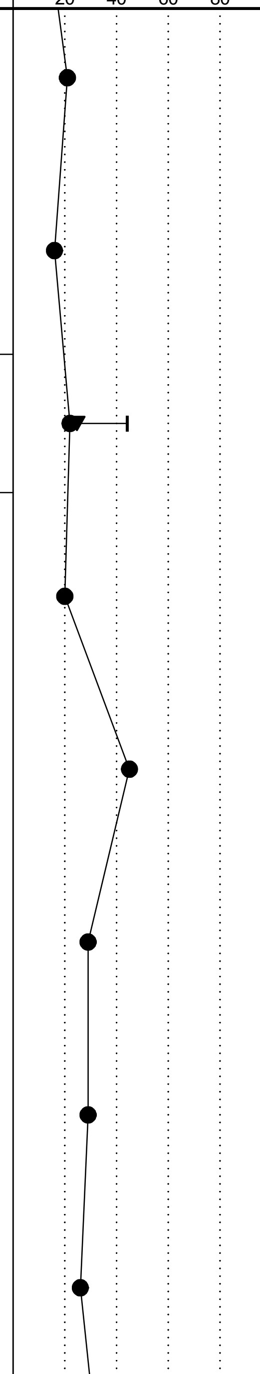
BORING LOG PR18-05

Project Name: Pretty Rocks
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3448 ft
Datum: MSL
Groundwater Depth:
While Drilling: ---
At Completion: ---
After Drilling: --- No groundwater encountered
Date Started: 8/3/18
Date Completed: 8/12/18
Driller/Company: Glen Rawson/Geotek Alaska
Drill: Geoprobe 6620 DT
Hammer Type: 140 lbs Automatic
Logger/Company: Orion George
Weather: Overcast
Notes:
VWP (S/N: 1816099); thermistor string to 48'

Elevation (ft)	Depth (ft)	MATERIAL DESCRIPTION	Drilling Method	Sample No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results
		Clayey GRAVEL with sand, loose, brown, moist, fine gravel, angular, no dilatancy, medium toughness, medium plasticity, with cobbles, ~30% sand. *(continued)* Moist, ~70% gravel and ~10% sand. 42.9° F measured	6.25" ID	S08	5-8-13-10 (18" = 75%)	
3425		Slow dilatancy, ~60% gravel and ~20% sand. 42.8° F measured		S09	10-7-9-10 (13" = 54%)	
	25	41.3° F measured		S10	8-10-12-11 (21" = 88%)	Fines = 18% SG = 2.75
		27.5 ft / El. 3420.5 ft				
3420		Clayey SAND with gravel, medium dense, brown, moist, medium sand, angular, ~40% sand and ~30% gravel, cobbles likely. 42.6° F measured		S11	8-4-16-20 (14" = 58%)	
	30	30 ft / El. 3418 ft				
		Clayey GRAVEL with sand, dense, brown, moist, fine gravel, angular, no dilatancy, medium toughness, medium plasticity, ~45% gravel and ~30% sand. 41.3° F measured		S12	15-30-15-17 (19" = 79%)	switch to casing advancer
3415		Medium dense. 41.9° F measured		S13	9-10-19-16 (20" = 83%)	
	35	~40% gravel and ~35% sand. 43.5° F measured		S14	9-15-14-14 (17" = 71%)	
		37.5 ft / El. 3410.5 ft				
3410		Clayey SAND with gravel, medium dense, brown, moist, medium sand, angular, no dilatancy, medium toughness, medium plasticity, cobbles likely. 41.5° F measured		S15	14-11-15-23 (18" = 75%)	"bit gumming up"

● N VALUE (20 40 60 80); PL WC LL (20 40 60 80); RQD (%) Recovery (%) (20 40 60 80)



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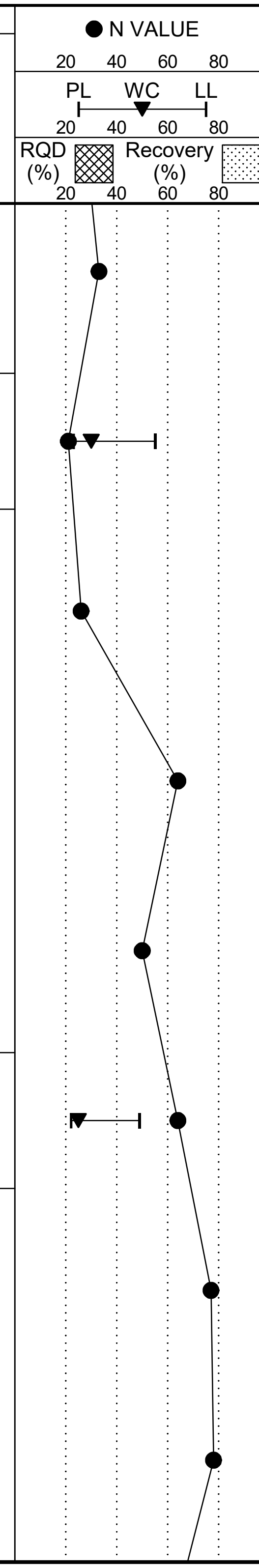
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-05

Project Name: Pretty Rocks
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3448 ft
Datum: MSL
Groundwater Depth:
While Drilling: ---
At Completion: ---
After Drilling: --- No groundwater encountered
Date Started: 8/3/18
Date Completed: 8/12/18
Driller/Company: Glen Rawson/Geotek Alaska
Drill: Geoprobe 6620 DT
Hammer Type: 140 lbs Automatic
Logger/Company: Orion George
Weather: Overcast
Notes:
VWP (S/N: 1816099); thermistor string to 48'

Drilling Method: tri-cone, compressed air

Elevation (ft)	Depth (ft)	Material Description	Sample No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results
		Clayey SAND with gravel, medium dense, brown, moist, medium sand, angular, no dilatancy, medium toughness, medium plasticity, cobbles likely. *(continued)* ~40% sand and ~30% gravel.	S16	11-16-17-15 (18" = 75%)	
3405		Medium to high toughness, medium to high plasticity, ~40% sand and ~25% gravel.	S17	6-12-9-18 (17" = 71%)	Fines = 26% SG = 2.79
	45	~45% sand and ~40% gravel, less clay, boulders likely. 47.8° F measured	S18	12-13-13-18 (23" = 96%)	
		47.5 ft / El. 3400.5 ft			
3400		Clayey GRAVEL with sand, very dense, tan to brown, moist, fine gravel, angular, ~50% gravel and ~30% sand.	S19	13-18-46-39 (24" = 100%)	
	50	~45% gravel and ~35% sand. 42.4° F measured	S20	14-25-25-26 (23" = 96%)	
3395		~60% gravel and ~25% sand. 44.2° F measured	S21	13-30-34-24 (22" = 92%)	Fines = 15% SG = 2.72
	55	55 ft / El. 3393 ft			
		Poorly graded GRAVEL with clay and sand, very dense, brown, moist, fine gravel, angular, ~45% gravel and ~40% sand, cobbles likely. 41.9° F measured	S22	13-30-47-29 (24" = 100%)	
3390		At 58.0' irregularly oriented ice and ice coating particles, ~20% visible ice, soft, cloudy and colorless to clear. 33.0° F measured	S23	23-29-49-43 (24" = 100%)	



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FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-05

Project Name: Pretty Rocks
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3448 ft Datum: MSL
Groundwater Depth:
While Drilling: ---
At Completion: ---
After Drilling: --- No groundwater encountered
Date Started: 8/3/18 Date Completed: 8/12/18
Driller/Company: Glen Rawson/Geotek Alaska Drill: Geoprobe 6620 DT
Hammer Type: 140 lbs Automatic
Logger/Company: Orion George
Weather: Overcast
Notes:
VWP (S/N: 1816099); thermistor string to 48'

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	N Value / PL, WC, LL / RQD, Recovery (%)
		Poorly graded GRAVEL with clay and sand, very dense, brown, moist, fine gravel, angular, ~45% gravel and ~40% sand, cobbles likely. *(continued)* ~60% visible ice, irregularly oriented with soil inclusions, clear to cloudy, hard, 60.5' to 62.0' preserved in freezer. 36.5° F measured	tri-cone, compressed air	S24	33-32-29-42 (25" = 104%)		
3385		~40% visible ice, irregularly oriented, 62.8' to 63.4' preserved in freezer.	tri-cone, compressed air	S25	38-28-50/6" (14" = 117%)		>>
	65	No ice observed.	tri-cone, compressed air	S26	8-14-50/5" (7" = 41%)		NP; >>
		67.5 ft / El. 3380.5 ft					
3380		Clayey SAND with gravel, very dense, brown to light tan, moist, medium sand, angular, no dilatancy, medium toughness, medium plasticity, unfrozen, cobbles likely.		S27	38-50/4" (9" = 90%)		>>
		68.2 ft / El. 3379.8 ft					
	70	Poorly graded SAND with gravel, very dense, light tan, dry, medium sand, angular.		S28	50/6" (5" = 83%)		
3375		73 ft / El. 3375 ft					
		Fat CLAY with sand, medium sand, angular, no dilatancy, high toughness, high plasticity. Light purplish buff, fine grained grained, highly weathered to completely weathered, extremely weak rock (R0). low recovery, no discontinuities observed.	HQ, compressed air				
	75		HQ, compressed air	R1	Rec = 3% RQD = 0%	switch to core	
3370		No recovery.	HQ, compressed air				

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-05

Project Name: Pretty Rocks
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3448 ft
Datum: MSL
Groundwater Depth:
While Drilling: ---
At Completion: ---
After Drilling: --- No groundwater encountered
Date Started: 8/3/18
Date Completed: 8/12/18
Driller/Company: Glen Rawson/Geotek Alaska
Drill: Geoprobe 6620 DT
Hammer Type: 140 lbs Automatic
Logger/Company: Orion George
Weather: Overcast
Notes:
VWP (S/N: 1816099); thermistor string to 48'

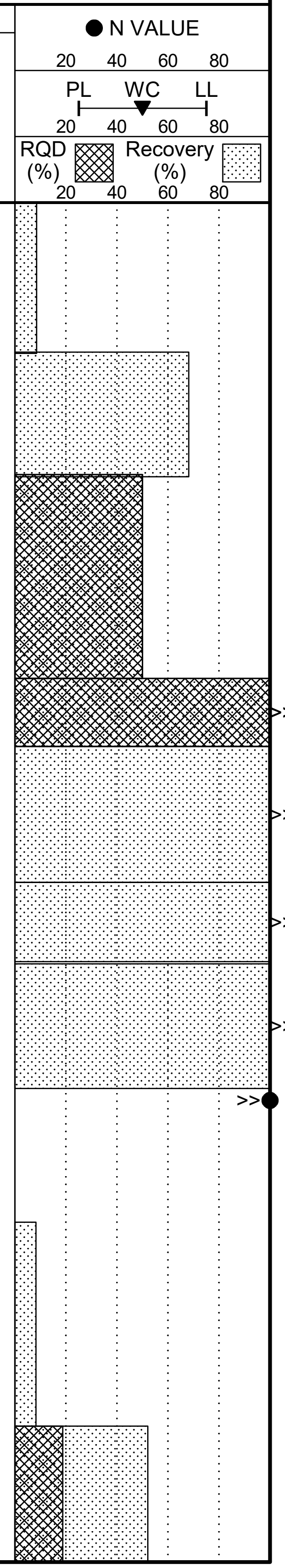
Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	N Value / RQD / Recovery
		Fat CLAY with sand, medium sand, angular, no dilatancy, high toughness, high plasticity. Light purplish buff, fine grained grained, highly weathered to completely weathered, extremely weak rock (R0). low recovery, no discontinuities observed. *(continued)*	HQ, compressed air	R2	Rec = 0% RQD = 0%		
3365		83 ft / El. 3365 ft		S29	50/5" (5" = 100%)		>>
	85			R3	Rec = 0% RQD = 0%		
3360				S30	27-50/5" (9" = 82%)		>>
	90			R4	Rec = 10% RQD = 0%		
3355	95			R5	Rec = 0% RQD = 0%		
3350		98 ft / El. 3350 ft		S31	50/4" (2" = 50%)		>>

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR18-05

Project Name: Pretty Rocks
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3448 ft
Datum: MSL
Groundwater Depth:
While Drilling: ---
At Completion: ---
After Drilling: --- No groundwater encountered
Date Started: 8/3/18
Date Completed: 8/12/18
Driller/Company: Glen Rawson/Geotek Alaska
Drill: Geoprobe 6620 DT
Hammer Type: 140 lbs Automatic
Logger/Company: Orion George
Weather: Overcast
Notes:
VWP (S/N: 1816099); thermistor string to 48'

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results
			HQ, compressed air	R6	Rec = 9% RQD = 0%	
3345				R7	Rec = 68% RQD = 0%	
	105			R8	Rec = 50% RQD = 50%	
		107 ft / El. 3341 ft		R9	Rec = 300% RQD = 300%	
3340				R10	Rec = 142% RQD = 0%	
	110			R11	Rec = 236% RQD = 0%	
				R12	Rec = 105% RQD = 0%	
3335				S32	50/5" (18" = 360%)	
				R13	Rec = 0% RQD = 0%	
	115	115 ft / El. 3333 ft		R14	Rec = 8% RQD = 0%	
3330		118.9 ft / El. 3329.1 ft perlite obsidian			Rec = 52%	

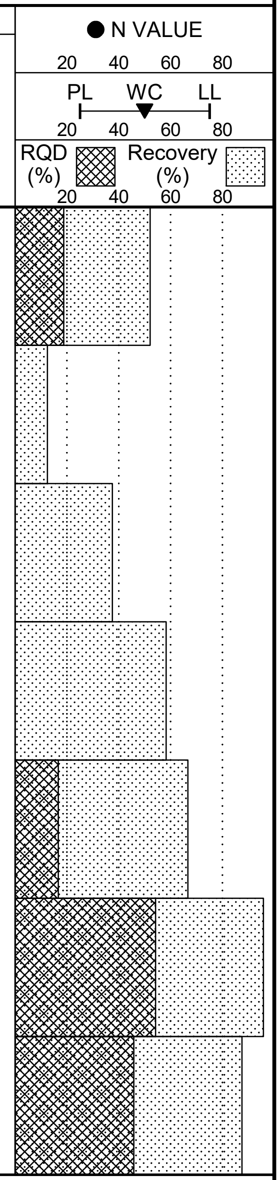


BORING LOG PR18-05

Project Name: Pretty Rocks
Sheet: 7 of 7
Project Location: Denali National Park and Preserve, Alaska
Surface Elevation: 3448 ft
Datum: MSL
Groundwater Depth:
Date Started: 8/3/18
Date Completed: 8/12/18
While Drilling: ---
Driller/Company: Glen Rawson/Geotek Alaska
Drill: Geoprobe 6620 DT
At Completion: ---
Hammer Type: 140 lbs Automatic
After Drilling: --- No groundwater encountered
Logger/Company: Orion George
Notes:
Weather: Overcast
VWP (S/N: 1816099); thermistor string to 48'

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results
			perlite obsidian *(continued)*	HQ, compressed air		R15	RQD = 19%	
3325						R16	Rec = 13% RQD = 0%	
	125					R17	Rec = 38% RQD = 0%	
						R18	Rec = 58% RQD = 0%	
3320						R19	Rec = 67% RQD = 17%	
	130					R20	Rec = 96% RQD = 54%	
3315			134 ft / El. 3314 ft			R21	Rec = 88% RQD = 46%	

Bottom of borehole at 134 ft.



U. S. DEPARTMENT OF TRANSPORTATION
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FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR19-07

Project Name: Pretty Rocks Landslide
Project Location: Denali National Park, Alaska
Latitude: 63.536276° Longitude: -149.81569°
Groundwater Depth:
While Drilling: 10.2 ft
At Completion: ---
After Drilling: 70.2 ft 10.2 to 70.2 ft.
Date Started: 9/7/19 Date Completed: 9/12/19
Driller/Company: Glen/GEOTEK AK Drill: CME-75
Hammer Type: 140 lbs Automatic
Logger/Company: RDD/S&W
Weather: 40's, night, windy

Notes:
VWPs ( ) installed at 90 ft depth.
Geophysical borehole survey conducted. Thermistor string installed 3 - 33 feet bgs (sensor every 2'). 3.34-inch slope inclinometer to 90 feet bgs.

Depth (ft)	MATERIAL DESCRIPTION	Drilling Method	Sample Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	N VALUE / RQD (%) / Recovery (%)
0	Poorly graded SAND with silt and gravel, dense, light brown to yellow, dry, angular, non plastic, with iron oxide staining. Interpeted as Fill.	CASING ADVANCER					
		CASING ADVANCER		S-1	17-16-19-26 (22" = 92%)		●
4	R1: No recovery, RCT = 6 min.	HQ3		R1	Rec = 0% RQD = 0%		
		HQ3		S-2	39-50/5" (7" = 64%)		>>●
9	Core loss 9.0 to 10.5 feet. Poorly graded GRAVEL with silt and sand, medium-dense to dense, gray to brown, moist, subangular to angular. RCT = 5 min. (groundwater 10.2 ft)	HQ3		R2	Rec = 50% RQD = 0%		
11.5 ft	R2: RHYOLITE, light brown to yellowish brown, fine grained, highly weathered, weak rock (R2). Discontinuities are extremely closely spaced and in very poor condition, with iron oxide staining.	HQ3					
	R3: Joint/fractures range from 60-80 degrees from assumed horizontal, with iron oxide staining, RCT = 8 min. Highly weathered to moderately weathered 13.3 to 17.7 feet.	HQ3		R3	Rec = 93% RQD = 0%		
17.7	Moderately weathered, less iron oxide staining 17.7 to 75.5 feet. R4: Joint/fractures range from 80-90 degrees from assumed horizontal, with iron oxide staining, RCT = 7 min.	HQ3					

BORING LOG PR19-07

Project Name: Pretty Rocks Landslide

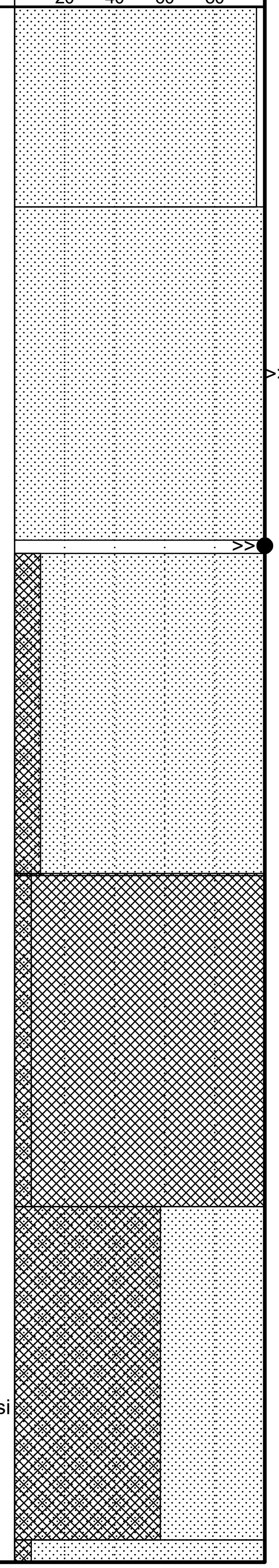
Project Location: Denali National Park, Alaska

Depth (ft)	Material Description	Drilling Method	Sample No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results
		HQ3	R4	Rec = 97% RQD = 0%	
	R5: Joint/fractures 70 degrees from assumed horizontal, with iron oxide staining, RCT = 9 min.				
25			R5	Rec = 103% RQD = 0%	
			S-3	50/2" (1" = 50%)	
	R6: Joint/fractures 80 degrees from assumed horizontal, with iron oxide staining, RCT = 8 min.				
30			R6	Rec = 100% RQD = 10%	
	R7: Joint/fractures 90 degrees from assumed horizontal, with clay infill, with iron oxide staining, RCT = 9 min.				
35			R7	Rec = 7% RQD = 100%	
	R8: Discountinuities are in good condition, joint/fractures range from 0-80 degrees from assumed horizontal, with iron oxide staining, RCT = 11 min.				
40			R8	Rec = 100% RQD = 58% FF = 10	UC = 7260 psi
	R9: Joint/fractures range from 0-90 degrees from				

● N VALUE (20, 40, 60, 80)

PL — WC — LL (20, 40, 60, 80)

RQD (%) / Recovery (%) (20, 40, 60, 80)



BORING LOG PR19-07

Project Name: Pretty Rocks Landslide

Project Location: Denali National Park, Alaska

Depth (ft)	MATERIAL DESCRIPTION	Drilling Method	No.	Core Rec., RQD, and Frac. Freq.	Test Results
	assumed horizontal, with iron oxide staining, RCT = 8 min.	HQ3			
45		HQ3	R9	Rec = 100% RQD = 7% FF = 10	
	R10: Joint/fractures range from 0-80 degrees from assumed horizontal, with iron oxide staining, RCT = 11 min.	HQ3			
50		HQ3	R10	Rec = 100% RQD = 22% FF = 4	
	R11: Joint/fractures range from 30-90 degrees from assumed horizontal, with iron oxide staining, RCT = 11 min.	HQ3			
55		HQ3	R11	Rec = 100% RQD = 0% FF = 10	
	R12: Joint/fractures range from 30-90 degrees from assumed horizontal, with iron oxide staining, RCT = 8 min. Weak rock (R2) to medium strong rock (R3) 58.1 to 93.8 feet. Discontinuities are in very poor condition, with clay infill at 59.3 feet.	HQ3			
60		HQ3	R12	Rec = 100% RQD = 52% FF = 3	
	R13: Joint/fractures range from 30-90 degrees from assumed horizontal, with iron oxide staining, RCT = 9 min.	HQ3			
65		HQ3	R13	Rec = 100% RQD = 10% FF = 10	

BORING LOG PR19-07

Project Name: Pretty Rocks Landslide

Project Location: Denali National Park, Alaska

Depth (ft)	Material Description	Drilling Method	Sample No.	Core Rec., RQD, and Frac. Freq.	Test Results
~67–68	R14: Joint/fractures range from 0-90 degrees from assumed horizontal, with iron oxide staining, RCT = 11 min. Vescular void at 68.7 feet.	HQ3			
70		HQ3	R14	Rec = 100% RQD = 18% FF = 10	
~73	R15: Joint/fractures range from 0-70 degrees from assumed horizontal, with iron oxide staining, RCT = 7 min. Discontinuities are in very poor condition, with clay infill at at 73.9 feet.	HQ3			UC = 4960 psi
75	Highly weathered, higher fractures from 75.5 to 76.0 feet. Moderately weathered 76.0 to 93.8 feet.	HQ3	R15	Rec = 100% RQD = 3% FF = 10	
~78	R16: Discountinuities are in good condition, joint/fractures range from 10-90 degrees from assumed horizontal, with iron oxide staining, RCT = 10 min.	HQ3			
80	Yellowish black to reddish brown 81.0 to 93.8 feet.	HQ3	R16	Rec = 100% RQD = 30% FF = 10	
~83	R17: Joint/fractures range from 40-90 degrees from assumed horizontal, with iron oxide staining, RCT = 11 min.	HQ3			
85	Discountinuities are in very poor condition, with greenish grey infill clay and quartz at 85.1 feet Flow banding at 87.0 feet.	HQ3	R17	Rec = 100% RQD = 35%	
~88	R18: Discountinuities are in good condition, joint/fractures range from 0-90 degrees from assumed horizontal, with iron oxide staining, RCT = 14 min. Perlite inclusions at 88.2 feet.	HQ3			UC = 1260 psi

BORING LOG PR19-07

Project Name: Pretty Rocks Landslide

Project Location: Denali National Park, Alaska

Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Sample Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	N VALUE / PL WC LL / RQD (%) Recovery (%)
			HQ3		R18	Rec = 100% RQD = 78%	UC = 4410 psi	
95		R19: Joint/fractures range from 70-90 degrees from assumed horizontal, with iron oxide staining, RCT = 16 min. Bluish grey to yellowish brown, extremely weak rock (R0) to weak rock (R2) 93.8 to 97.3 feet. Highly weathered to completely weathered below 93.8 feet. Occasional pockets of gravel below 96.0 feet Ice inclusions, Vx, hard, clear, colorless, approximately 0.5 inch diameter at 97.0 feet Light grey to yellowish brown, medium strong rock (R3) below 97.3 feet.	HQ3		R19	Rec = 100% RQD = 10%		
100		R20: Joint/fractures range from 0-70 degrees from assumed horizontal, with iron oxide staining, RCT = 10 min.	HQ3		R20	Rec = 100% RQD = 14%		
		100.7 ft						

Water levels obtained day after bailing excavation; due to subsurface conditions may not indicate accurate groundwater levels.
VWP S/N 1901649 installed to 90.0 feet bgs.
Thermistor string installed 3 - 33 feet bgs (sensor every 2'). 3.34-inch slope inclinometer installed to 90 feet bgs.

Bottom of borehole at 100.3 ft.

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR19-08

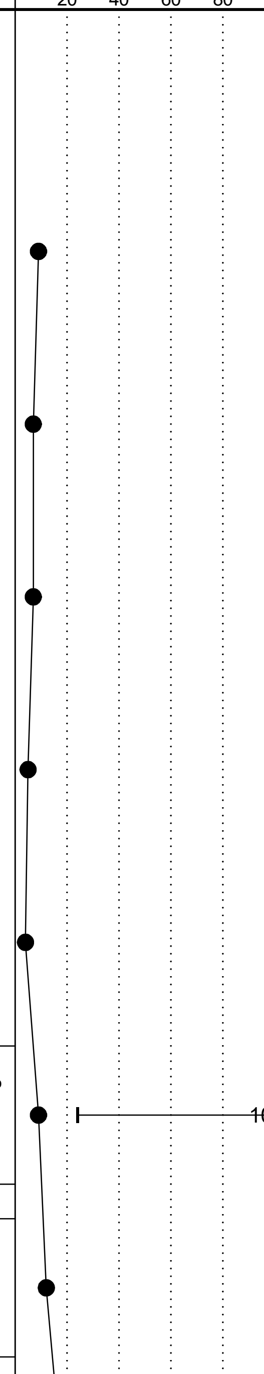
Project Name: Pretty Rocks Landslide
Project Location: Denali National Park, Alaska
Latitude: 63.536892° Longitude: -149.817512°
Groundwater Depth:
While Drilling: 89.8 ft
At Completion: ---
After Drilling: ---
Date Started: 8/31/19 Date Completed: 9/4/19
Driller/Company: Glen/GEOTEK AK Drill: CME-75
Hammer Type: 140 lbs Automatic
Logger/Company: RDD/JLD/S&W
Weather: 40's, night, windy

Notes:
VWPs ( ) installed at 93 ft depth.
Geophysical survey performed following drilling. Thermistor string installed 0 - 32 feet bgs (sensor every 2 feet). 3.34-inch slope inclinometer installed to 100 feet bgs.

Depth (ft)	Material Description
0 – 4.75 ft	Clayey GRAVEL with sand, loose, brown to dark brown, moist, angular, disrupted. Interpeted as Fill.
4.75 – 11.5 ft	Poorly graded GRAVEL with silt and sand, loose, dark brown to light yellow, moist, angular, disrupted.
11.5 – 11.9 ft	Clayey SAND, very loose, yellow to brown, moist, angular.
11.9 – 19.8 ft	Fat CLAY, soft, yellow to brown, moist, high plasticity, blocky. Residual Rhyolite and Ash Tuff completely weathered, extremely weak rock.

Drilling Method: CASING ADVANCER

No.	Field Blow Count (Recovery)	Test Results
S-1	2-5-4-3 (18" = 75%)	
S-2	3-4-3-1 (13" = 54%)	
S-3	2-4-3-1 (10" = 42%)	
S-4	3-4-1-1 (12" = 50%)	
S-5	2-2-2-2 (11" = 46%)	
S-6	3-4-5-7 (17" = 71%)	Fines = 59% SG = 2.75 Temp. = 41.2°F
S-7	3-5-7-7 (24" = 100%)	Temp. = 55.1°F



BORING LOG PR19-08

Project Name: Pretty Rocks Landslide
Project Location: Denali National Park, Alaska

Depth (ft)	MATERIAL DESCRIPTION	Drilling Method	Sample Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results
	RHYOLITE, loose, yellowish brown to light grey, moist, fine grained, completely weathered to highly weathered, extremely weak rock (R0) to very weak rock (R1). weathered to fat clay with sand. *(continued)*	CASING ADVANCER		S-8	5-8-10-9 (24" = 100%)	Temp. = 40.2°F
				S-9	8-11-26 (18" = 100%)	Temp. = 42.3°F
23.6 ft	BASALT, dark grey, fine grained, olivine inclusions, slightly weathered to fresh, weak rock (R2) to medium strong rock (R3).					
24 ft	RHYOLITE, yellowish brown to dark grey, fine grained, basalt and perlite linclusions, completely weathered to highly weathered, extremely weak rock (R0) to very weak rock (R1), residual soil is clayey GRAVEL with sand, moist, fine to coarse gravel. Occasional quartz infill in joints.					
25				S-10	5-11-11-16 (24" = 100%)	Temp. = 41.0°F
				S-11	9-30-35-50/6" (22" = 94%)	Temp. = 42.3°F
30				S-12	50/5" (5" = 100%)	Temp. = 43.7°F
35				S-13	50/5" (4" = 80%)	Temp. = 43.0°F
				S-14	9-9-50/2" (0" = 0%)	
40 ft	BASALT, slightly vesicular, grey to reddish brown, fine grained, slightly weathered to fresh, strong rock (R4) to very strong rock (R5). R1: Discontinuities are closely spaced to very closely spaced and in good condition. Joint/fractures range from 30-60 degrees from assumed horizontal, with iron oxide staining, RCT = 8 min.	HQ3		R1	Rec = 100% RQD = 86% FF = 2	UC = 8210 psi
	R2: Joint/fractures range from 20-90 degrees from					

N VALUE: >> (S-11, S-12, S-13, S-14)

PL WC LL; RQD (%); Recovery (%)

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FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR19-08

Project Name: Pretty Rocks Landslide

Project Location: Denali National Park, Alaska

Depth (ft)	MATERIAL DESCRIPTION	Drilling Method	Sample No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results
	assumed horizontal, with iron oxide staining, RCT = 11 min. BASALT, slightly vesicular, grey to reddish brown, fine grained, slightly weathered to fresh, strong rock (R4) to very strong rock (R5). R1: Discontinuities are closely spaced to very closely spaced and in good condition. Joint/fractures range from 30-60 degrees from assumed horizontal, with iron oxide staining, RCT = 8 min. *(continued)*	HQ3	R2	Rec = 100% RQD = 57% FF = 6	
45	Slightly weathered to moderately weathered 47.3 to 47.8 feet. Slightly weathered to fresh 47.8 to 75.0 feet. R3: Joint/fractures range from 70-90 degrees from assumed horizontal, with iron oxide staining, RCT = 8 min.	HQ3	R3	Rec = 100% RQD = 43% FF = 10	
50	R4: Joint/fractures range from 10-90 degrees from assumed horizontal, with iron oxide staining, RCT = 9 min.	HQ3	R4	Rec = 97% RQD = 27% FF = 10	
55	Core loss 58.0 to 58.2 feet. R5: Joint/fractures range from 70-90 degrees from assumed horizontal, with iron oxide staining, RCT = 7 min.	HQ3	R5	Rec = 100% RQD = 0% FF = 10	
60	R6: Joint/fractures range from 10-90 degrees from assumed horizontal, with iron oxide staining, RCT = 20 min.	HQ3	R6	Rec = 100% RQD = 44% FF = 5	
65	R7: Joint/fractures range from 60-70 degrees from assumed horizontal, with iron oxide staining, RCT = 23 min.	HQ3	R7	Rec = 100% RQD = 83% FF = 3	

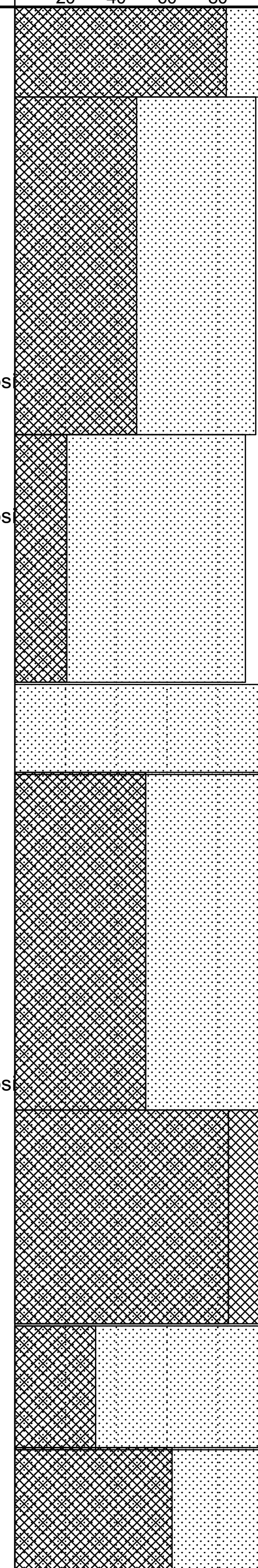
N VALUE: 20 40 60 80 — PL WC LL: 20 40 60 80 — RQD (%) / Recovery (%): 20 40 60 80

BORING LOG PR19-08

Project Name: Pretty Rocks Landslide

Project Location: Denali National Park, Alaska

Depth (ft)	Material Description	Drilling Method	Sample No.	Core Rec., RQD, and Frac. Freq.	Test Results
	Quartz veinlets at 67.7 feet.	HQ3			
	R8: Joint/fractures range from 0-70 degrees from assumed horizontal, with iron oxide staining, RCT = 10 min.	HQ3	R8	Rec = 95% RQD = 48% FF = 10	UC = 22070 psi
69 ft	Void 69.0 to 69.3 feet.				
69.3 ft (70)					
	R9: Joint/fractures range from 0-90 degrees from assumed horizontal, with iron oxide staining, RCT = 12 min. Core loss 73.0 to 73.3 feet.	HQ3	R9	Rec = 91% RQD = 20% FF = 10	UC = 26500 psi
75 ft	Highly weathered, with clay infill 75.0 to 75.25 feet.				
75.25 ft	Slightly weathered to fresh below 75.25 feet.				
	R10: Joint/fractures range from 10-90 degrees from assumed horizontal, with iron oxide staining, RCT = 6 min.	HQ3	R10	Rec = 100% RQD = 0% FF = 10	
(80)	R11: Joint/fractures range from 0-90 degrees from assumed horizontal, with iron oxide staining, RCT = 23 min.	HQ3	R11	Rec = 100% RQD = 52% FF = 10	UC = 10510 psi
(85)	R12: Joint/fractures range from 10-90 degrees from assumed horizontal, with iron oxide staining, RCT = 12 min.	HQ3	R12	Rec = 84% RQD = 97% FF = 10	
	R13: Joint/fractures range from 0-70 degrees from assumed horizontal, with iron oxide staining, RCT = 7 min.	HQ3	R13	Rec = 100% RQD = 32%	
	R14: Joint/fractures range from 10-75 degrees from assumed horizontal, with iron oxide staining, RCT = 17 min.	HQ3			



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FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR19-08

Project Name: Pretty Rocks Landslide

Project Location: Denali National Park, Alaska

Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Sample Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	N VALUE / PL WC LL / RQD (%) Recovery (%)
		Slightly weathered to fresh below 75.25 feet. *(continued)*	HQ3		R14	Rec = 100% RQD = 62% FF = 7	UC = 14020 psi	
95		R15: Joint/fractures range from 30-90 degrees from assumed horizontal, with iron oxide staining, RCT = 15 min.			R15	Rec = 100% RQD = 57% FF = 4	UC = 31020 psi	
100		R16: Joint/fractures range from 20-75 degrees from assumed horizontal, with iron oxide staining, RCT = 14 min. Occasional quartz mineralization in vescules at 98.5 feet.			R16	Rec = 100% RQD = 43% FF = 10	UC = 21170 psi	
		103 ft						

Water levels obtained day after bailing excavation before drilling started. Due to subsurface conditions indicated groundwater levels may not be accurate. VWP S/N 1901650 installed to 93.0 feet. Thermistor string installed 0 - 32 feet bgs (sensor every 2 feet). 3.34-inch slope inclinometer installed to 100 feet bgs.

Bottom of borehole at 103 ft.

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BORING LOG PR19-11

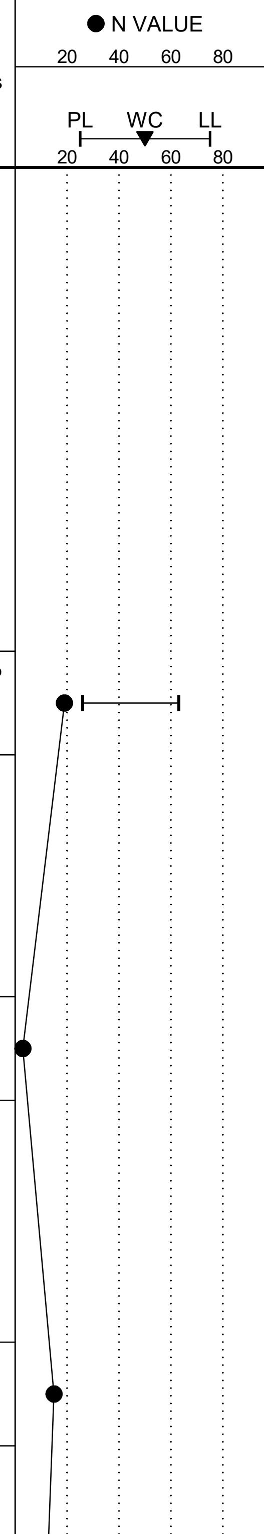
Project Name: Pretty Rocks Landslide
Project Location: Denali National Park, Alaska
Latitude: 63.534009° Longitude: -149.819308°
Groundwater Depth:
While Drilling: 23.4 ft
At Completion: ---
After Drilling: 64 ft
Date Started: 9/12/19 Date Completed: 9/22/19
Driller/Company: Travis/GEOTEK AK Drill: Geoprobe 8040DT
Hammer Type: 140 lbs Automatic
Logger/Company: RDD/S&W
Weather: 40-50's, partly cloudy, windy

Notes:
VWPs ( ) installed at 55, 98 ft depth.
Thermistor string installed 0 - 105 feet bgs (sensors: 0 - 50 ft every 2 ft & 50 - 105 ft every 5 feet). 3.34-inch slope inclinometer installed to 157 feet bgs.

Depth (ft)	Material Description	Drilling Method
0 – 10.3 ft	Elastic SILT with sand, stiff, yellow and brown to dark gray, moist. Frozen (Vr), random ice inclusions up to 1/2 inch in diameter and up to 1 inch in length; cloudy ; disrupted; perlite inclusions.	CASING ADVANCER
10.3 – 15.5 ft	Silty SAND, very loose, yellow and brown to black, moist, trace gravel. Frozen (Vx) visible ice crystals 1mm to 3mm in size; cloudy; disrupted; perlite inclusions.	CASING ADVANCER
15.5 – 19.5 ft	Elastic SILT, stiff, yellow and brown to light gray, moist, trace gravel. Frozen (Vx) visible ice crystals 1mm to 3mm in size; cloudy; homogeneous.	CASING ADVANCER
19.5 ft	*(description on next page)*	CASING ADVANCER

SAMPLE

Type	No.	Field Blow Count (Recovery)	Test Results
Split spoon	S-1	5-8-11 (18" = 100%)	Fines = 33% SG = 2.46 Temp. = 32.0°F
Split spoon	S-2	3-2-1 (18" = 100%)	Temp. = 32.7°F
Split spoon	S-3	4-6-9 (18" = 100%)	Temp. = 31.9°F



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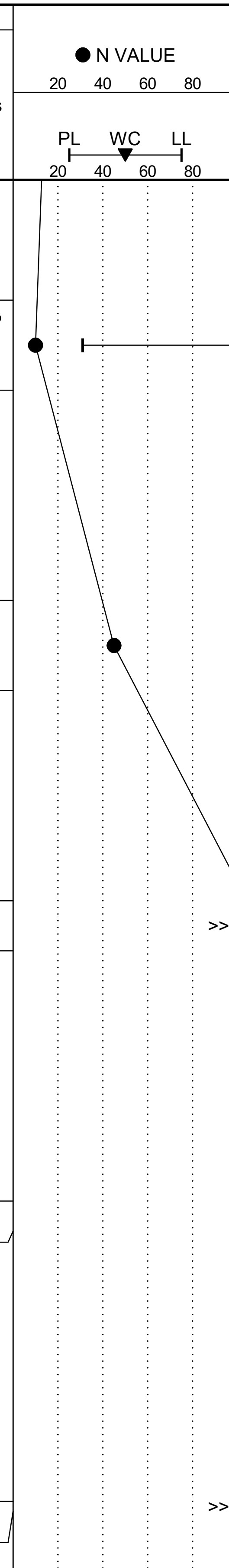
BORING LOG PR19-11

Project Name: Pretty Rocks Landslide

Project Location: Denali National Park, Alaska

Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Sample Type	No.	Field Blow Count (Recovery)	Test Results
		Fat CLAY, stiff, yellow and brown to light gray, moist. Frozen (Vr), random ice inclusions up to 1/2 inch in diameter and up to 1 inch in length; cloudy; homogeneous. *(continued)*	CASING ADVANCER				
					S-4	4-4-6 (18" = 100%)	Fines = 78% SG = 2.63 Temp. = 32.3°F
		∇					
25		25.5 ft					
		COBBLES, very dense, light brown.					
		Sandy GRAVEL, light gray to light brown. Frozen (Vr), random ice inclusions up to 1/4 inch in dimaeter; cloudy; homogeneous. Sample 5A was frozen and is stored in NPS freezer at Denali National Park.			S-5	12-9-36 (17" = 94%)	Temp. = 32.1°F
30							
					S-6	29-50/4" (10" = 100%)	Temp. = 32.4°F
		34 ft					
35		Ice, hard, (Vs), ice lenses up to 1 inch thick and 2 1/2 inches long oriented approximately 60 degrees from horizontal; cloudy; rhyolite inclusions and gravel with cobbles in ice.					
		Sample 7 was frozen and is stored in NPS freezer at Denali National Park.			S-7	50 (6" = 100%)	Temp. = 31.6°F
40							
		Sample 8 was frozen and is stored in NPS freezer at Denali National Park.			S-8	50/2" (2" = 100%)	Temp. = 38.5°F



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FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR19-11

Project Name: Pretty Rocks Landslide

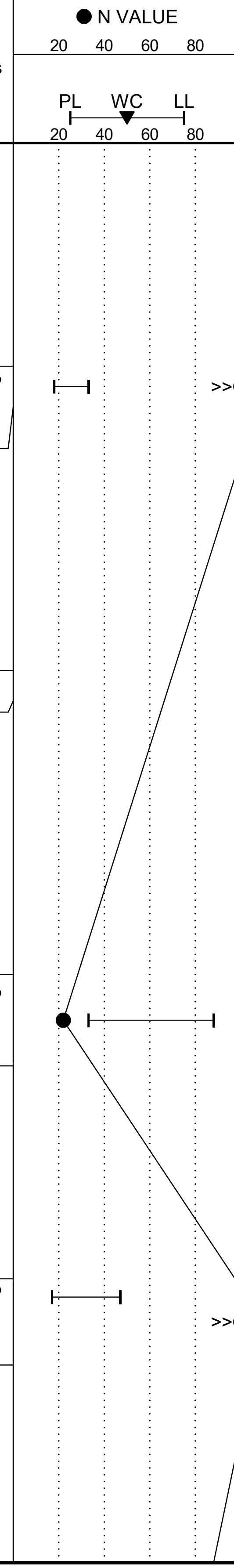
Project Location: Denali National Park, Alaska

Depth (ft)	MATERIAL DESCRIPTION
44.5 ft	Silty SAND with gravel, very dense, light brown, moist. Frozen (Vr), visible ice inclusions up to 1 inch wide and 1 inch long; cloudy; disrupted; 1-inch hard cobbles inferred from drilling action at 47.5 feet.
	Sample 10 was frozen and is stored in NPS freezer at Denali National Park.
55 ft	Fat CLAY, very stiff, gray, moist, trace fine sand; homogeneous. Occcasional weathered rhyolite gravel.
62.3 ft	Silty SAND with gravel, very dense, yellow and brown to gray, moist, iron oxide staining, angular gravel.
66 ft	Sandy GRAVEL with clay; with basalt cobbles below 66.0 feet.

Drilling Method: CASING ADVANCER

SAMPLE

No.	Field Blow Count (Recovery)	Test Results
S-9	26-50/2" (8" = 100%)	Fines = 17% SG = 2.64 Temp. = 32.6°F
S-10	50 (6" = 100%)	Temp. = 33.1°F
S-11	3-10-12 (18" = 100%)	Fines = 78% SG = 2.66 Temp. = 40.1°F
S-12	11-21-50/5" (17" = 100%)	Fines = 26% SG = 2.75 Temp. = 44.1/45.9°F



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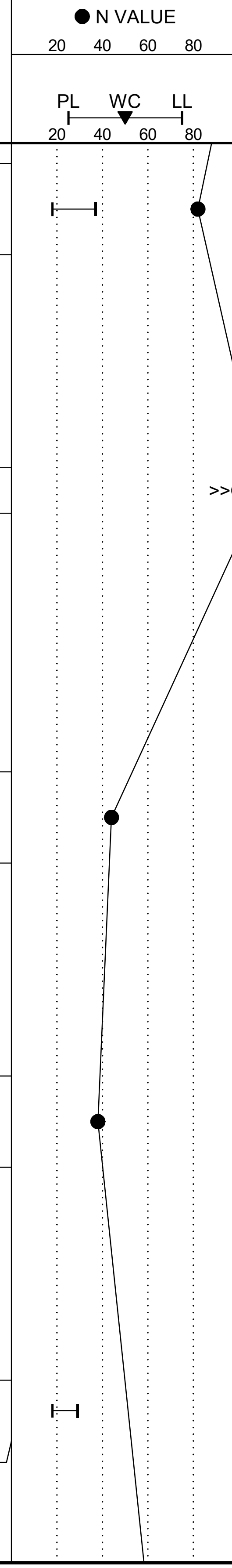
BORING LOG PR19-11

Project Name: Pretty Rocks Landslide

Project Location: Denali National Park, Alaska

Depth (ft)	MATERIAL DESCRIPTION	Drilling Method	Type	No.	Field Blow Count (Recovery)	Test Results
	Sandy GRAVEL with clay; with basalt cobbles below 66.0 feet. *(continued)*	CASING ADVANCER		S-13	38-40-42 (14" = 78%)	Fines = 12% SG = 2.75 Temp. = 43.9°F
70	70 ft — Silty GRAVEL with sand, very dense, yellow and brown to gray, moist, iron oxide staining; disrupted, Angular cobbles inferred from drilling with basalt inclusions.					
	Sample 14 was frozen and is stored in NPS freezer at Denali National Park.			S-14	20-50/3" (9" = 100%)	Temp. = 42.3°F
75	75 ft — Silty SAND, dense, brown to gray, moist, trace gravel; disrupted. Angular to subangular gravel.			S-15	11-21-23 (5" = 28%)	Temp. = 43.9°F
80	80 ft — Fat CLAY, very stiff, yellow and brown to light gray, trace sand, trace gravel, iron oxide staining, Coarse sand; homogeneous; basalt nodule in shoe; rounded gravel.			S-16	6-10-28 (18" = 100%)	Temp. = 43.4°F
85	85 ft — Silty SAND with gravel, very dense, brown to dark gray, moist, subrounded to rounded sand and gravel, disrupted, mostly rhyolite.			S-17	20-50 (10" = 83%)	Fines = 14% SG = 2.72 Temp. = 43.7°F



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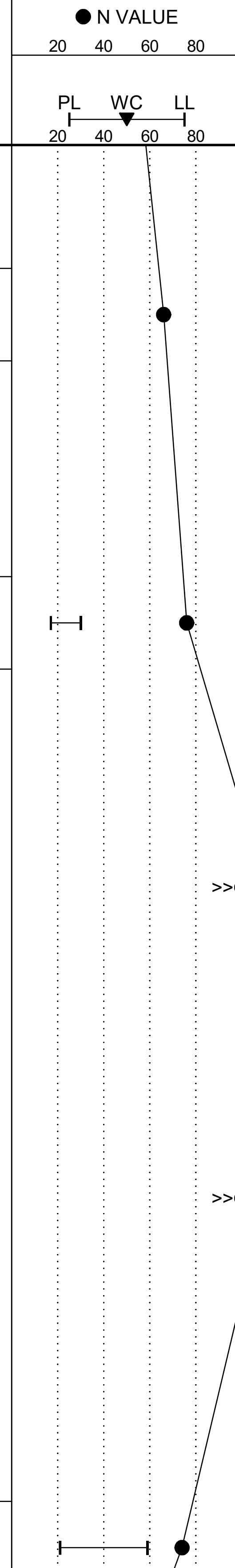
FEDERAL LANDS HIGHWAY DIVISION

BORING LOG PR19-11

Project Name: Pretty Rocks Landslide

Project Location: Denali National Park, Alaska

Depth (ft)	MATERIAL DESCRIPTION	Drilling Method	Type	No.	Field Blow Count (Recovery)	Test Results
	Gravel more angular and basaltic below 90.0 feet.	CASING ADVANCER				
				S-18	30-32-34 (15" = 83%)	Temp. = 48.6°F
95	95 ft					
	Silty GRAVEL with sand, very dense, brown, moist, subrounded to angular gravel, disrupted.					
				S-19	20-41-35 (13" = 72%)	Fines = 17% SG = 2.67 Temp. = 48.0/47.7°F
100	100 ft					
	No recovery from samples taken at 102.0 and 107.0 feet, rhyolite inferred based on drilling action and residue on split spoon.					
				S-20	50/1" (0" = 0%)	
105						
				S-21	50/2" (0" = 0%)	
110	110 ft					
	RHYOLITE TUFF, bluish grey, moist, fine grained, residual soil, extremely weak rock (R0). Completely weathered to fat clay.					
				S-22	20-32-42 (18" = 100%)	Fines = 84% SG = 2.71 Temp. =



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BORING LOG PR19-11

Project Name: Pretty Rocks Landslide

Project Location: Denali National Park, Alaska

Depth (ft)	Material Description	Drilling Method	Sample Type	Sample No.	Field Blow Count (Recovery)	Test Results
113		CASING ADVANCER				43.7°F
115						
118				S-23	15-15-10 (18" = 100%)	Temp. = 41.9°F
120						
123				S-24	20-26-39 (18" = 100%)	Temp. = 40.7°F
125	125 ft Fat CLAY with sand and gravel, very stiff, blue to gray, moist, angular gravel, disrupted.					
128				S-25	29-50 (12" = 100%)	Fines = 27% SG = 2.71 Temp. = 39.8°F
130						
133				S-26	29-50/2" (8" = 100%)	Temp. = 35.8°F
135	135 ft RHYOLITE, bluish grey, moist, fine grained, residual soil, extremely weak rock (R0). Completely weathered to fat clay.					

N VALUE: 20 40 60 80 (S-26: >>)

PL WC LL: 20 40 60 80

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BORING LOG PR19-11

Project Name: Pretty Rocks Landslide

Project Location: Denali National Park, Alaska

Depth (ft)	Material Description	Drilling Method	Sample No.	Field Blow Count (Recovery)	Test Results	N Value
~137		CASING ADVANCER	S-27	18-23-30 (18" = 100%)	Temp. = 39.0°F	53
~142		CASING ADVANCER	S-28	29-50 (12" = 100%)	Fines = 87% SG = 2.71 Temp. = 38.1°F	
147.0	No recovery from samples taken at 147.0, 152.0, and 157.0 feet, rhyolite inferred based on drilling action and residue on split spoon.	CASING ADVANCER	S-29	50/2" (0" = 0%)		>>
152.0		CASING ADVANCER	S-30	50/1" (0" = 0%)		>>
157.0	157.1 ft	CASING ADVANCER	S-31	50/1" (0" = 0%)		>>

Water levels obtained after bailing borehole, and before drilling. Due to subsurface conditions groundwater levels may not be accurate.
VWP S/N 1902185 installed to 55.0 feet and VWP S/N 1932186 installed to 98.0 feet.

Bottom of borehole at 157.1 ft.

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BOREHOLE LOG LEGEND

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska

MATERIAL TYPE SYMBOLS

Poorly Graded Gravel

Gravel/Sand

Poorly Graded Sand

Sand/Clay

High Plasticity Clay

Rhyolite

Basalt

Perlite

SAMPLE TYPE SYMBOLS

Standard Penetration Test (2"OD)

S01 = SPT Sample

R01 = Rock Core Sample

DRILLING METHOD SYMBOLS

Casing Advancer

HQ Core

ABBREVIATIONS

CRT	- Core Run Time
E	- Modulus of Elasticity
FF	- Fracture Frequency (fractures per foot)
Fines	- Percent Passing No.200 Sieve
JRC	- Joint Roughness Coefficient
LL	- Liquid Limit (%)
NP	- Non-Plastic
PL	- Plastic Limit (%)
PLT	- Point Load Test
PP	- Pocket Penetrometer Reading
psi	- pounds per square inch
Rec	- Rock Core Recovery
RQD	- Rock Quality Designation
SG	- Specific Gravity
S/N	- Serial Number
UC	- Unconfined Compressive Strength
VWP	- Vibrating Wire Piezometer
WC	- Water Content (%)

BOREHOLE LOG LEGEND

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska

SECONDARY CONSTITUENTS

Descriptive Adjective (2)	Percentage Requirements (3)
trace	<10%
some	10 - 20%
y/ey	20 - 35%
and	>35%

(1) Secondary Constituent determination for Silt and Clay based on 0.002 mm grain size boundary if hydrometer was performed.
(2) Acceptable Secondary Constituents: Clay, Silt, Sand, Gravel, Cobbles, Boulders.
(3) Descriptive terms based on estimated percentage by weight.

APPARENT DENSITY OF COARSE-GRAINED SOIL

SPT N-value (blows per foot)	Apparent Density
0 to 4	Very Loose
5 to 10	Loose
11 to 30	Medium Dense
31 to 50	Dense
>50	Very Dense

CONSISTENCY OF FINE-GRAINED SOIL

SPT N-value (blows per foot)	Consistency
0 to 1	Very Soft
2 to 4	Soft
5 to 8	Firm
9 to 15	Stiff
16 to 30	Very Stiff
>30	Hard

WEATHERING / ALTERATION (ISRM 1978)

GRADE	DESCRIPTION	FIELD IDENTIFICTION
A/W 1	- Fresh and Unweathered	- No visible sign of rock material weathering
A/W 1.5	- Faintly Weathered	- Discolouration on major discontinuity surfaces
A/W 2	- Slightly Weathered or Altered	- Discolouration indicated weathering of rock material and discontinuity surfaces. All rock material may be discoloured by weathering and may be weaker than in its fresh condition
A/W 3	- Moderately Weathered or Altered	- Less than 50% of rock material decomposed and/or disintegrated to soil. Fresh/discoloured rock present as a continuous framework or corestones
A/W 4	- Highly Weathered or Altered	- More than 50% rock material is decomposed or disintegrated to soil. Fresh/Discoloured rock present as discontinuous framework or corestones
A/W 5	- Completely Weathered or Altered	- All rock material decomposed and/or disintegrated to soil original mass structure still largely intact
A/W 6	- Residual Soil	- All rock material converted to soil: mass structure and material fabric destroyed

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BOREHOLE LOG LEGEND

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska

FIELD STRENGTH GRADE (ISRM 1978 & 1981)

GRADE	FIELD IDENTIFICATION	DESCRIPTION	UCS (MPa)
R6	- Specimen can only be chipped with flat end of geological hammer	Extremely Strong	> 250
R5	- Specimen requires many blows of flat end of geological hammer to fracture	Very Strong	100-250
R4	- Specimen requires more than one blow of flat end of geological hammer to fracture	Strong	50-100
R3	- Cannot be scraped or peeled with pocket knife; can be fractured with single firm blow of flat end of the geologic hammer	Medium Strong	25-50
R2	- Can be peeled by a pocket knife with difficulty; shallow indentation made by firm blow with point of geological hammer	Weak	5-25
R1	- Crumbles under firm blow with point of geological hammer; can be peeled by a pocket knife	Very Weak	1-5
R0	- Indented by thumbnail	Extremely Weak	< 0.2 - 1

DISCONTINUITY CONDITION (ISRM 1978, 1981)

Condition	Description
Excellent Condition	- Very rough surfaces, no separation, hard discontinuity wall(>R2).
Good Condition	- Slightly rough surfaces, separation less than ~0.04 inches (1 mm), hard discontinuity wall(>R2).
Fair Condition	- Slightly rough surface, separation greater than ~0.04 inches (1 mm), soft discontinuity wall(<R3).
Poor Condition	- Slickensided surfaces, or soft gouge less than ~0.2 inches (5 mm) thick, or open discontinuities between ~0.4 and 0.2 inches (1 to 5 mm)
Very Poor Condition	- Soft gouge greater than ~0.2 inches (5 mm), or open discontinuities greater than ~0.2 inches (5 mm).

DISCONTINUITY SPACING (INCLUDES JOINTS/FRACTURES, BEDDING, AND FAULTS)

Description	Spacing of Discontinuity
Extremely Widely Spaced	>20 feet (>6 m)
Very Widely Spaced	~6 to 20 feet (2 to 6 m)
Widely Spaced	~2 to 6 feet (600 mm to 2 m)
Moderately Spaced	~8 inches to 2 feet (200 mm to 600 mm)
Closely Spaced	~2 to 8 inches (60 to 200 mm)
Very Closely Spaced	~3/4 to 2 inches (20 to 60 mm)
Extremely Closely Spaced	~3/4 inches (<20 mm)

BOREHOLE LOG PR21-01

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska
Surface Elevation: 3632.07 ft
Latitude: 63.53626° Longitude: -149.81579° Datum: NAD 1983
Date Started: 7/11/21 Date Completed: 7/13/21
Driller/Company: Aaron Devalle/Haztech Drill CS 1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: clear, night, 40's-50's F

Notes:
Purpose: East abutment investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Material Description	Sample Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results
	0.0–1.5	0.0' to 1.5': Poorly graded GRAVEL, grey, dry, fine to coarse, subrounded to subangular, with cobbles, subrounded to subangular. [Interpreted as Fill.] 1.5 ft				
3630	1.5–12	1.5' to 12': Poorly graded GRAVEL with sand, dense to very dense, moist, light grey to yellow, fine to coarse, subangular to angular, rhyolite gravel with orange iron staining on surfaces, with fine to coarse sand, trace silt. [Interpreted to be highly weathered rhyolite.]				
	3.0–4.5		SPT	S01	10-19-22 (18"=100%)	
3625	6.0	6.0': Water circulation lost				
	8.0–8.3		SPT	S02	50/3" (3"=83%)	

N VALUE 20 40 60 80; PL WC LL 20 40 60 80; RQD (%) Recovery (%) 20 40 60 80

BOREHOLE LOG PR21-01

Project Name: Polychrome Area Improvements

Project Location: Denali National Park, Alaska
Surface Elevation: 3632.07 ft
Latitude: 63.53626° Longitude: -149.81579° Datum: NAD 1983
Date Started: 7/11/21 Date Completed: 7/13/21
Driller/Company: Aaron Devalle/Haztech Drill CS 1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: clear, night, 40's-50's F

Notes:
Purpose: East abutment investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample No.	Core Rec., RQD, and Frac. Freq.	Test Results
	11	(12 ft)				
3620	12	12.0' to 84.6': RHYOLITE, light grey to yellow, fine grained, slightly vesicular, highly weathered to slightly weathered, very weak rock (R1) to strong rock (R4), with iron staining on fracture surfaces.	HQ3			
	13	12.0' to 29.5': Moderately weathered, weak (R2) to medium strong (R3) rock.		R1	Rec= 94% RQD=25% FF=5	
	14	R1: Run Core Time (RCT) = 6 min. Discontinuities are very closely to closely spaced, in fair condition, at 20 to 40 degrees from assumed horizontal, with iron staining and sand infilling.				
3615	15–18	R2: RCT = 8 min. Discontinuities are very closely to closely spaced, in fair to good condition, at 15-25 degrees and 40-50 degrees from assumed horizontal, with iron staining, sand and silt infilling. Some iron oxide infilled veins and vesicles.		R2	Rec= 100% RQD=47% FF=3	
	19			UC1		UC=3221 psi

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BOREHOLE LOG PR21-01

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Project Location: Denali National Park, Alaska
Surface Elevation: 3632.07 ft
Latitude: 63.53626° Longitude: -149.81579° Datum: NAD 1983
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Driller/Company: Aaron Devalle/Haztech Drill CS 1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: clear, night, 40's-50's F

Notes:
Purpose: East abutment investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results
	20–21	R3: RCT = 10 min. Discontinuities are extremely closely to closely spaced, in poor condition, at 20-40 degrees from assumed horizontal, with iron staining, open fractures and vesicles up to 2 mm.	HQ3	R3	Rec= 100% RQD=47% FF=4	
3610	21.5	21.5' to 24.0': Highly fractured, weak (R2) rock.	HQ3	R3		
	25	R4: RCT = 9 min. Discontinuities are very closely to closely spaced, in fair to poor condition.	HQ3	R4	Rec= 100% RQD=37% FF=3	
3605	27–28		HQ3	R4 UC2		UC=9891 psi
	29.5	29.5': Joint at 45 degrees from assumed horizontal, in very poor condition, infilled with ice (Vx, clear, hard), and dark brown high plasticity clay and silt.	HQ3			

N VALUE: 20 40 60 80
PL WC LL: 20 40 60 80
RQD (%) / Recovery (%): 20 40 60 80

BOREHOLE LOG PR21-01

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska
Surface Elevation: 3632.07 ft
Latitude: 63.53626° Longitude: -149.81579° Datum: NAD 1983
Date Started: 7/11/21 Date Completed: 7/13/21
Driller/Company: Aaron Devalle/Haztech Drill CS 1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: clear, night, 40's-50's F

Notes:
Purpose: East abutment investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample No.	Core Rec., RQD, and Frac. Freq.	Test Results
	29.5–31	29.5' to 38.0': Highly weathered, very weak (R1) rock, fractured and brecciated. Some zones up to 6 inches are completely weathered to silty sand with gravel.	HQ3			
3600	32	R5: RCT = 8 min. Discontinuities are extremely closely spaced, in very poor to poor condition,with iron staining, some structure lost. Brecciated with angular rhyolite gravel in a silty sand matrix.	HQ3	R5	Rec= 97% RQD=0% FF=10	
	35	R6: RCT = 11 min. 35.0' to 38.0': Discontinuiteis are extremely closely to very closely spaced, brecciated as above. 38.0' to 40.0': Discontinuities are very closely spaced, in poor to fair condition, at 40-60 degrees from assumed horizontal, with iron staining, and sand and silt infilling, JRC's 6-8.	HQ3	R6	Rec= 100% RQD=0% FF=6	
3595	38	38.0' to 42.5': Moderately weathered, weak (R2) to medium strong (R3) rock.	HQ3	R6		

Depth marks: 31, 32, 33, 34, 35, 36, 37, 38, 39

N VALUE: 20 40 60 80
PL WC LL: 20 40 60 80
RQD (%) / Recovery (%): 20 40 60 80

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BOREHOLE LOG PR21-01

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska
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Latitude: 63.53626° Longitude: -149.81579° Datum: NAD 1983
Date Started: 7/11/21 Date Completed: 7/13/21
Driller/Company: Aaron Devalle/Haztech Drill CS 1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: clear, night, 40's-50's F

Notes:
Purpose: East abutment investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	N VALUE / PL WC LL / RQD (%) Recovery (%)
	40–45		R7: RCT = 8 min. Discontinuities are extremely closely to closely spaced, in very poor to fair condition, at 30-50 degrees from assumed horizontal, with iron staining, and sand and silt infilling. 41.0': Slickensides at 45 degrees from assumed horizontal. . 42.5' to 44.0':Highly weathered, very weak (R1) rock, brecciated with slickensides on some discontinuity surfaces. 44.0' to 54.0': Moderately weathered, weak (R2) to medium strong (R3) rock.	HQ3		R7	Rec= 100% RQD=13% FF=6			
3590	42									
	45–50		R8: RCT = 12 min. Discontinuities are very closely to closely spaced, in very poor to fair condition, at 20-90 degrees from assumed horizontal, with iron staining, sand and silt infilling, with slickensides on some fracture surfaces. Several fractures at 80-90 degrees from assumed horizontal occur along brecciated veins/fractures.	HQ3		R8	Rec= 98% RQD=0% FF=3			
3585	47									

BOREHOLE LOG PR21-01

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

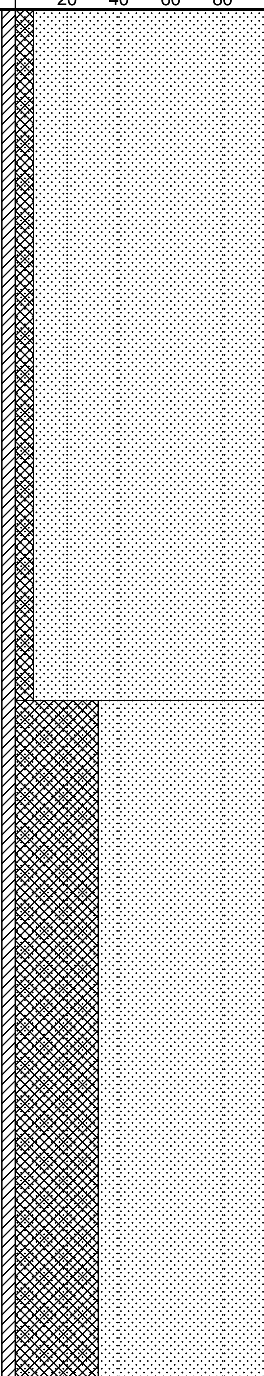
Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska

Surface Elevation: 3632.07 ft
Latitude: 63.53626° Longitude: -149.81579° Datum: NAD 1983
Date Started: 7/11/21 Date Completed: 7/13/21
Driller/Company: Aaron Devalle/Haztech Drill CS 1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: clear, night, 40's-50's F

Notes:
Purpose: East abutment investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample Type	Sample No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results
	50.0–51	R9: RCT = 11 min. Some quartz mineralization. Discontinuities are very closely to closely spaced, in fair to good condition, at 20-40 degrees from assumed horizontal, with iron staining.	HQ3		R9	Rec= 100% RQD=7% FF=4	
3580	52						
	53						
	54	54.0' to 65.0': Slightly weathered, medium strong (R3) to strong (R4) rock.					
	55	R10: RCT = 9 min. Discontinuities are closely spaced, in good condition, at 40-55 degrees from assumed horizontal, with iron staining, and trace sand infilling on several fractures.	HQ3		R10	Rec= 100% RQD=32% FF=4	
	56						
3575	57						
	58						
	59						

N VALUE: 20 40 60 80
PL WC LL: 20 40 60 80
RQD (%) / Recovery (%): 20 40 60 80



U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BOREHOLE LOG PR21-01

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska
Surface Elevation: 3632.07 ft
Latitude: 63.53626° Longitude: -149.81579° Datum: NAD 1983
Date Started: 7/11/21 Date Completed: 7/13/21
Driller/Company: Aaron Devalle/Haztech Drill CS 1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: clear, night, 40's-50's F

Notes:
Purpose: East abutment investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Sample Type	Sample No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	N VALUE / PL WC LL / RQD (%) Recovery (%)
			R11: RCT = 13 min. Discontinuities are closely spaced, in good condition, at 30-50 degrees from assumed horizontal, with iron staining.	HQ3						
	61									
3570	62					R11	Rec= 100% RQD=50% FF=3			
	63									
	64									
	65		65.0' to 68.0': Moderately weathered, weak (R2) rock.							
	66		R12: RCT = 10 min. Discontinuities are extremely closely to very closely spaced, in very poor to poor condition, at 30-50 degrees and 80-90 degrees from assumed horizontal, with iron staining.							
3565	67					R12	Rec= 100% RQD=0% FF=7			
	68		68.0' to 70.0': Highly weathered, very weak (R1) rock, some structure lost, with disseminated iron staining, and some silty sand.							
	69									

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BOREHOLE LOG PR21-01

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska
Surface Elevation: 3632.07 ft
Latitude: 63.53626° Longitude: -149.81579° Datum: NAD 1983
Date Started: 7/11/21 Date Completed: 7/13/21
Driller/Company: Aaron Devalle/Haztech Drill CS 1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: clear, night, 40's-50's F

Notes:
Purpose: East abutment investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	N VALUE / PL WC LL / RQD (%) Recovery (%)
			70.0' to 75.0': Moderately weathered, weak (R2) rock.	HQ3						
	71		R13: RCT = 8 min. Rhyolite with grey, white, and orange flow bands ranging from 0.2 to 1.0 inches thick. Discontinuities are very closely to closely spaced, in poor to fair condition, and typically occur along flow bands at 30-45 degrees and at 60-70 degrees from assumed horizontal, with iron staining, and clayey sand infilling.							
3560	72					R13	Rec= 100% RQD=22% FF=3			
	73		73.0': Joint, at 65 degrees from assumed horizontal, with clayey sand infilling and slickensides at 55 degrees.							
	74		73.8': 0.8-inches of clay, moist, white, high plasticity, no dilatancy, sticky to touch.							
	75		75.0' to 84.0': Slightly weathered, medium strong (R3) to strong (R4) rock.							
	76									
3555	77		R14: RCT = Not recorded. Rhyolite, light grey to yellow with dark grey inclusions and flow banding, fine-grained, vesicular. Discontinuities are closely to moderately spaced, in good condition, at 30-40 and 60-70 degrees from assumed horizontal, with iron staining.			R14	Rec= 100% RQD=67% FF=2			
	78									
	79									

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BOREHOLE LOG PR21-01

Project Name: Polychrome Area Improvements
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Surface Elevation: 3632.07 ft
Latitude: 63.53626° Longitude: -149.81579° Datum: NAD 1983
Date Started: 7/11/21 Date Completed: 7/13/21
Driller/Company: Aaron Devalle/Haztech Drill CS 1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: clear, night, 40's-50's F

Notes:
Purpose: East abutment investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	N VALUE / PL WC LL / RQD (%) Recovery (%)
	80–84.6	R15: RCT = Not recorded. Discontinuities are moderately spaced, in good condition, at 30-40 and 60-70 degrees from assumed horizontal, some mechanical breaks. Some chlorite and phaneritic quartz, vesicular.	HQ3		R15	Rec= 100% RQD=78% FF=1			
3550	82								
	84	84.0': Joint, at 20 degrees from assumed horizontal, with 0.2-inch aperture, infilled with white clayey sand ,and ice (Vx, clear, hard, lenticular). 84.6 ft							
	84.6–87	84.6' to 87.0': Completely weathered, extremely weak (R0) rock, white to light grey. [Clayey SAND with gravel, fine to coarse sand, medium to high plasticity clay, frozen.] 87 ft							
3545	87–88.1	87.0' to 88.1': ICE with clayey sand inclusions, Vx, clear, vitreous, hard, with some bubbles. 88.1 ft			R16	Rec= 95% RQD=0%			
	88.1–	87.0' to 91.5': Completely weathered, extremely weak (R0) rock, white to light grey. [Clayey SAND with gravel, fine to coarse sand, medium to high plasticity clay, frozen.]							

BOREHOLE LOG PR21-01

Project Name: Polychrome Area Improvements
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Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: clear, night, 40's-50's F

Notes:
Purpose: East abutment investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample Type	Sample No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	N VALUE / PL WC LL / RQD (%) Recovery (%)
	90	90.0': ICE preserved in the core barrel shoe, Vx, clear, vitreous, hard. (91.5 ft)	HQ3						
3540	91.5–95	91.5' to 100.0': Completely weathered, extremely weak (R0) rock. [Sandy CLAY, light blue-grey to dark green-grey, hard, moist, high plasticity, no dilatancy, shiny, sticky to touch, with some iron staining, with some rhyolite clasts from 91.5' to 93.5'.	HQ3		R17	Rec= 100% RQD=0%			
3535	95–97.5		HQ3		R18	Rec= 53% RQD=0%			
	97.5–100	(100 ft)	HQ3		R19	Rec= 100% RQD=0%			>>

BOREHOLE LOG PR21-01

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska

Surface Elevation: 3632.07 ft
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Date Started: 7/11/21 Date Completed: 7/13/21
Driller/Company: Aaron Devalle/Haztech Drill CS 1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: clear, night, 40's-50's F

Notes:
Purpose: East abutment investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	SAMPLE Type	No.	Field Blow Count (Recovery) Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	● N VALUE 20 40 60 80; PL WC LL 20 40 60 80; RQD (%) Recovery (%) 20 40 60 80

Notes:

1) 100.0': End of Borehole.
2) Depth to water measured at 11.5' on 07-12-21, approximately 19 hours after drilling. Due to subsurface conditions and the use of drilling water, water levels may not be representative.
3) Geophysical acoustic televiewer survey conducted from approximately 12.0' to 83.0'.
4) Schedule 80 PVC casing (2.0" inner diameter) installed to 100.0'. The borehole was tremie grouted to surface through 0.5" PVC with cement bentonite grout using an approximate ratio of 25 gallons of water: 1 bag (92.5 lbs) of cement: 15 lbs of bentonite. Additional grout was added through the tremie tube as casing was removed from the borehole.
5) Downhole geophysical seismic survey conducted.
6) Shape Acceleration Array (SAA) installed from 0.0' to 89.0'. Prior to SAA installation, the PVC was observed to be impassable below 89.0', likely due to ice in the casing. The SAA was installed to the maximum depth possible.
7) Field strength R values were assigned based on field observations of intact rock samples and assigned strength grades may not be equivalent to point load or unconfined compressive strength test results.
8) Completely to highly weathered material was dual classified with both rock and soil descriptions based on field observations. Field soil USCS classifications may not be consistent with grain size distribution and/or plasticity values from soil laboratory testing as difficulties in processing the soil-like weathered rock were reported to BGC by the lab.

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BOREHOLE LOG PR21-01a

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska
Sheet: 1 of 2
Surface Elevation: 3632 ft
Latitude: 63.53626° Longitude: -149.81579° Datum: NAD 1983
Date Started: 7/14/21 Date Completed: 7/14/21
Driller/Company: Aaron Devalle/Haztech Drill CS 1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: windy, night, 40's F

Notes:
Purpose: Additional information for the upper 15 feet of PR21-01. See end of log notes.

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Sample Type	Sample No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	N VALUE / PL WC LL / RQD (%) Recovery (%)
	0		0.0' to 10.0': Poorly graded GRAVEL, white to yellow, moist, fine to coarse, subangular to angular, rhyolite gravel, trace sand, some cobbles likely. [Interpreted to be highly weathered rhyolite bedrock.]	HQ3						
	1									
3630	2		R1: RCT=not recorded.			R1	Rec= 40% RQD=0%			
	3									
	4									
	5		5.0' to 6.5': Driller reported that "the ground felt soft and the drill rods dropped." R2: RCT = 6 min.							
	6									
3625	7					R2	Rec= 30% RQD=0%			
	8									
	9		10 ft							

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BOREHOLE LOG PR21-01a

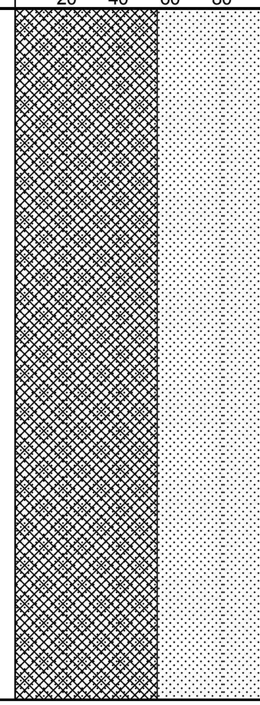
Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska

Surface Elevation: 3632 ft
Latitude: 63.53626° Longitude: -149.81579° Datum: NAD 1983
Date Started: 7/14/21 Date Completed: 7/14/21
Driller/Company: Aaron Devalle/Haztech Drill CS 1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: windy, night, 40's F

Notes:
Purpose: Additional information for the upper 15 feet of PR21-01. See end of log notes.

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details
	10		10' to 15': RHYOLITE, white to yellow, fine grained, slightly vesicular, slightly weathered, medium strong (R3) rock.						
	11								
3620	12		R3: RCT = 8 min. Discontinuities are closely spaced, in fair condition, at 30-40 degrees and 50-60 degrees from assumed horizontal, with iron staining on fracture surfaces.	HQ3		R3	Rec= 98% RQD=55% FF=3		
	13								
	14								
	15		15 ft						

● N VALUE (20 40 60 80); PL WC LL (20 40 60 80); RQD (%) / Recovery (%) (20 40 60 80)



Notes:

1) 17.0': End of Borehole.
2) Groundwater not encountered.
3) No instrumentation installed.
4) Borehole backfilled with cuttings and bentonite chips.

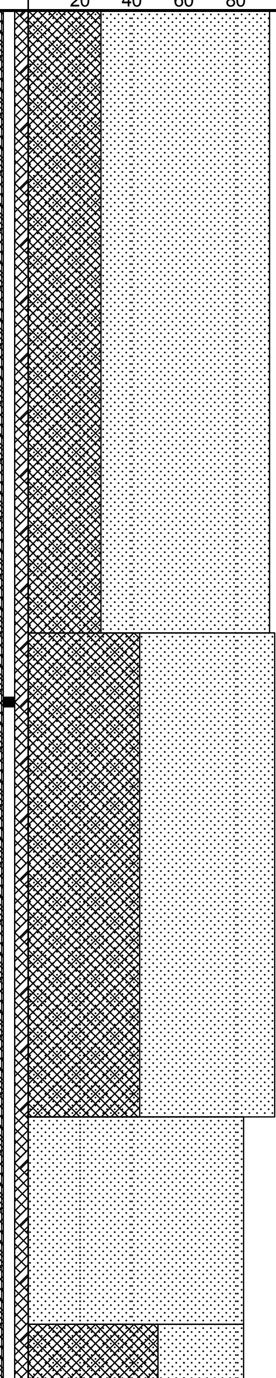
BOREHOLE LOG PR21-02

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska
Surface Elevation: 3629.73 ft
Latitude: 63.53619° Longitude: -149.81478° Datum: NAD 1983
Date Started: 8/9/21 Date Completed: 8/9/21
Driller/Company: Aaron Devalle/Haztech Drill CS1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: overcast, rain, day, 40's-50's F

Notes:
Azimuth: 290 Dip: 70
Purpose: East cut slope investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results
	0–1	0.0' to 1.0': Poorly graded GRAVEL, grey, dry, fine to coarse, subangular to subrounded, with clayey sand gravel coatings. [Interpreted as Fill.] 1 ft	HQ3		R1	Rec= 93% RQD=28% FF=4	
	1–4.5	1.0' to 16': RHYOLITE, light grey to yellow, fine grained, slightly vesicular, highly weathered to slightly weathered, weak rock (R2) to strong rock (R4), with iron staining on fracture surfaces. R1: Run Core Time (RCT) = 15 min. Discontinuities are closely spaced, in fair to good condition, at 30 to 45 degrees and 60-70 degrees to core axis, with iron staining and sand infilling, JRC's 8-10.	HQ3		R1		
3625	4.5–8	R2: RCT = 12 min. Rhyolite with dark red inclusions and quartz phenocrysts. Discontinuities are very closely to moderately spaced, in fair to good condition, at 15 to 40 degrees to core axis, with iron staining and sand infilling. One fracture is at 85 degrees to core axis, JRC's 8-14.	HQ3		UC1 / R2	Rec= 95% RQD=43% FF=3	UC=6016 psi
	8–9.5	R3: RCT = 8 min. Discontinuities are closely spaced, in fair condition, at 30 to 70 degrees to core axis, with iron staining, JRC's 8-12. 8.0': 50% water circulation.	HQ3		R3	Rec= 83% RQD=0% FF=6	



U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BOREHOLE LOG PR21-02

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska
Surface Elevation: 3629.73 ft
Latitude: 63.53619° Longitude: -149.81478° Datum: NAD 1983
Date Started: 8/9/21 Date Completed: 8/9/21
Driller/Company: Aaron Devalle/Haztech Drill CS1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: overcast, rain, day, 40's-50's F

Notes:
Azimuth: 290 Dip: 70
Purpose: East cut slope investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample Type	No.	Core Rec., RQD, and Frac. Freq.	Test Results
3620	11	R4: RCT = 9 min. Discontinuities are closely spaced, in fair to good condition, at 40 to 65 degrees to core axis, JRC's 8-16.	HQ3		R4	Rec= 83% RQD=50% FF=3	
	12–13	R5: RCT = 9 min. Discontinuities are closely spaced, in poor to good condition, at 20 to 30 degrees and 70 to 90 degrees to core axis, with iron staining and clayey sand infilling, JRC's 10-14. With grey, yellow, and red flow bands up to 0.8 inches.	HQ3		R5	Rec= 100% RQD=17% FF=4	
	13		HQ3		UC2		UC=5924 psi
3615	15	R6: RCT = 6 min. Discontinuities are extremely closely spaced to very closely spaced, in poor condition, at 10 to 30 degrees and 70 to 80 degrees to core axis, with clayey sand infilling, JRC's 8-14. 15.7' to 16.0': Gravel with clay, light grey, high plasticity, with some sand. (16 ft)	HQ3		R6	Rec= 72% RQD=0% FF=13	
	16–19	16.0' to 19.5': BASALT, black with red and white flow banding, fine grained, slightly weathered, strong (R4) rock, with iron staining on fracture surfaces, some flow bands are folded. R7: RCT = 11 min. Discontinuities are very closely spaced to closely spaced, in very poor to fair condition, at 20 to 40 degrees and 60 to 70 degrees to core axis, with clayey sand infilling, JRC's 4-12. (19.5 ft)	HQ3		R7	Rec= 67% RQD=14% FF=5	
	19.5	19.2' to 19.5': Discontinuity at 25 degrees to core axis, with a 3-inch zone of brecciated basalt with clay, orange to green, moist, high plasticity, no dilatancy,	HQ3				

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BOREHOLE LOG PR21-02

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska
Surface Elevation: 3629.73 ft
Latitude: 63.53619° Longitude: -149.81478° Datum: NAD 1983
Date Started: 8/9/21 Date Completed: 8/9/21
Driller/Company: Aaron Devalle/Haztech Drill CS1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: overcast, rain, day, 40's-50's F

Notes:
Azimuth: 290 Dip: 70
Purpose: East cut slope investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	N VALUE / PL WC LL / RQD (%) Recovery (%)
			high toughness.							
3610	21		19.5' to 21.0': CLAY, light green-grey, hard (PP > 4.5), moist, high plasticity, no dilatancy, high toughness. R8: RCT = 13 min. Discontinuities are closely spaced, in very poor to fair condition, at 40 to 60 degrees to core axis, JRC's 14-18. 21 ft	HQ3		R8	Rec= 73% RQD=0%			
	22		21.0' to 23.3': PERLITE, black, fine grained, homogenous to platy, moderately weathered, very weak (R1) to weak (R2) rock. R9: RCT = 10 min. Core loss. Recovered core is gravel sized particle of perlite. 23.3 ft							
	23–24		23.3' to 24.8': Sandy CLAY, light green-grey, hard, moist, high plasticity, no dilatancy, high toughness, with some fine, subangular gravel, some sand. 24.8 ft			R9	Rec= 40% RQD=0%			
	25–26		R10: RCT = 9 min. Structure lost. 24.5' to 34.5': Completely weathered, extremely weak (R0) rock, some remnant flow banding apparent at 20 to 30 degrees to core axis, most structure lost. [Poorly graded SAND, very dense, brown to grey, fine sand, with some zones up to 6 inches of clayey sand and clay.]			R10	Rec= 100% RQD=0%			
3605	27–28		R11: RCT = 10 min. Some structure likely lost. Discontinuities are closely spaced to moderately spaced, in very poor condition, at 30 to 45 degrees and 60 to 70 degrees to core axis, JRC's 10-12.			R11	Rec= 93% RQD=0%			
	29		R12: RCT = 10 min. Some structure likely lost. Discontinuities are closely spaced to moderately spaced, in very poor condition, at 30 to 45 degrees and 60-70 degrees to core axis.							

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BOREHOLE LOG PR21-02

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska
Surface Elevation: 3629.73 ft
Latitude: 63.53619° Longitude: -149.81478° Datum: NAD 1983
Date Started: 8/9/21 Date Completed: 8/9/21
Driller/Company: Aaron Devalle/Haztech Drill CS1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: overcast, rain, day, 40's-50's F

Notes:
Azimuth: 290 Dip: 70
Purpose: East cut slope investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results
3600	29.5–34.5	29.5': Discontinuity at 45 degrees to core axis with high plasticity clay and slickensides. (34.5 ft)	HQ3		R12	Rec= 100% RQD=0%	
3595	34.5–37	34.5' to 42.0': Completely weathered, extremely weak (R0) rock. [Clayey SAND, very dense, moist, blue-grey to green-grey, fine sand, high plasticity clay, some bands of clay, with some orange oxidized veins.] R13: RCT = 8 min. Structure lost. R14: RCT = 6 min. Structure lost.	HQ3		R13	Rec= 100% RQD=0%	
	37–39.5		HQ3		R14	Rec= 100% RQD=0%	

N VALUE: 20 40 60 80; PL WC LL: 20 40 60 80; RQD (%) / Recovery (%): 20 40 60 80

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BOREHOLE LOG PR21-02

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska
Surface Elevation: 3629.73 ft
Latitude: 63.53619° Longitude: -149.81478° Datum: NAD 1983
Date Started: 8/9/21 Date Completed: 8/9/21
Driller/Company: Aaron Devalle/Haztech Drill CS1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: overcast, rain, day, 40's-50's F

Notes:
Azimuth: 290 Dip: 70
Purpose: East cut slope investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Sample Type	Sample No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	N VALUE / PL WC LL / RQD (%) Recovery (%)
	41		R15: RCT = 14 min. 39.5' to 43.5': Structure lost. 43.5' to 44.5': Discontinuities are closely spaced, in poor to fair condition, at 50 to 60 degrees to core axis, with iron staining, and clayey sand infilling, JRC's 8-14.	HQ3						
3590	42		42.0' to 43.5': Highly weathered, extremely weak (R0) rock, with some intact rhyolite corestones.			R15	Rec= 100% RQD=13%			
	43		43.5 ft							
	44		43.5' to 49.5': RHYOLITE, light grey to yellow, fine grained, vesicular, moderately weathered, weak (R2) rock, with flow banding. 44.0' to 45.5': Flow banding is folded.							
	45									
	46									
	47		R16: RCT = 16 min. Discontinuities are very closely to closely spaced, in poor to fair condition, at 10 to 80 degrees to core axis, with iron staining, and clayey sand infilling, JRC's 8-14.			R16	Rec= 100% RQD=17% FF=5			
3585	48		47.8' to 49.5': Very weak (R1) rock with clayey sand.							
	49		49.5 ft							

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BOREHOLE LOG PR21-02

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska
Surface Elevation: 3629.73 ft
Latitude: 63.53619° Longitude: -149.81478° Datum: NAD 1983
Date Started: 8/9/21 Date Completed: 8/9/21
Driller/Company: Aaron Devalle/Haztech Drill CS1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: overcast, rain, day, 40's-50's F

Notes:
Azimuth: 290 Dip: 70
Purpose: East cut slope investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	SAMPLE Type	SAMPLE No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	N VALUE 20 40 60 80 / PL WC LL 20 40 60 80 / RQD (%) Recovery (%) 20 40 60 80

Notes:

1) 49.5': End of borehole.
2) Depth to water measured at 13.4' at 08:40 am 08-10-21, approximately 19 hours after the completion of drilling. Due to subsurface conditions and the use of drilling water, water levels may not be representative. Haztech pumped water out of the borehole for approximately 30 minutes, after 20 minutes of rest, the depth to water was measured at 30.4'.
3) Geophysical televiewer survey attempted on 9-Aug-2021, the borehole caved at 9.0' and 14.5'. The survey was abandoned due to subsurface conditions.
4) Schedule 40 PVC (1" inner diameter) installed to 30.4'. The borehole was tremie grouted to the ground surface through 0.5" PVC with approximately 30 gallons of cement bentonite grout using an approximate ratio of 25 gallons of water: 1.3 bags (92.5 lbs.) of cement: 10 lbs. of bentonite. Additional grout was added through the tremie tube as casing was removed from the borehole.
5) VWP (S/N #2020979) installed at 48.9' on August 10, 2021. A protective flush mount monument was installed at the borehole collar. A thermistor string with 5-foot sensor spacing was installed on September 2, 2021. A VWP data logger ,configured to a collection interval of every 12 hours and a thermistor data logger, configured to a collection interval of every 24 hours were installed on September 2, 2021.
6) Field strength R values were assigned based on field observations of intact rock samples and assigned strength grades may not be equivalent to point load or unconfined compressive strength test results.
7) Completely to highly weathered material was dual classified with both rock and soil descriptions based on field observations.

BOREHOLE LOG PR21-07

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska

Surface Elevation: 3630.8 ft
Latitude: 63.53612° Longitude: -149.81506° Datum: NAD 1983
Date Started: 8/29/21 Date Completed: 8/30/21
Driller/Company: Aaron Devalle/Haztech Drill CS 1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: partly cloudy, 20's-30's F

Notes:
Purpose: East construction platform investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Sample Type	Sample No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	N VALUE / PL WC LL / RQD (%) Recovery (%)
	0		0' to 25.5': Poorly graded GRAVEL with clay and sand, loose to medium dense, orange to white to light red, moist, fine to coarse, subangular rhyolite gravel, some fine to coarse sand, trace clay.	HQ3						
3630	1									
	2		R1: Run Core Time (RCT) = 8 min.			R1	Rec= 15% RQD=0%			
3625	5.5		R2: RCT = 7 min.			S01	4-6-7 (8"=44%)			
	7		7.0': Water circulation lost.			R2	Rec= 13% RQD=0%			

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BOREHOLE LOG PR21-07

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska

Surface Elevation: 3630.8 ft
Latitude: 63.53612° Longitude: -149.81506° Datum: NAD 1983
Date Started: 8/29/21 Date Completed: 8/30/21
Driller/Company: Aaron Devalle/Haztech Drill CS 1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: partly cloudy, 20's-30's F

Notes:
Purpose: East construction platform investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Sample Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	N VALUE / PL WC LL / RQD (%) Recovery (%)
3620	11			HQ3		S02	1-3-2 (2"=11%)			
	11.5		R3: RCT = Not recorded.							
	12–15					R3	Rec= 32% RQD=0%			
3615	15.5–16		R4: RCT = 7 min.			S03	7-11-9 (7"=39%)			
	17–19					R4	Rec= 35% RQD=0%			

BOREHOLE LOG PR21-07

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska
Surface Elevation: 3630.8 ft
Latitude: 63.53612° Longitude: -149.81506° Datum: NAD 1983
Date Started: 8/29/21 Date Completed: 8/30/21
Driller/Company: Aaron Devalle/Haztech Drill CS 1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: partly cloudy, 20's-30's F

Notes:
Purpose: East construction platform investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample Type	Sample No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	N Value / RQD / Recovery (%)
3610	21	R5: RCT=11 min.	HQ3	Split spoon	S04	6-9-4 (9"=50%)			
	23		HQ3	Core	R5	Rec= 28% RQD=0%			
	25.5	25.5 ft							
3605	26	25.5' to 30.0': Completely weathered, extremely weak (R0) rock, with remnant flow banding apparent, frozen with ICE crystals up to 0.75 inches long, Vx, Vr, clear to cloudy, hard. [GRAVEL and CLAY with sand, hard (PP > 4.5), yellow-brown to blue-grey, moist, high plasticity, no dilatancy, high toughness, with some fine to coarse, subangular sand, and some fine to coarse, subangular rhyolite gravel.] R6: RCT=15 min.	HQ3	Split spoon	S05	13-48-50/2" (13"=90%)			
	28		HQ3	Core	R6	Rec= 72% RQD=0%			
	30	30 ft							

BOREHOLE LOG PR21-07

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska
Surface Elevation: 3630.8 ft
Latitude: 63.53612° Longitude: -149.81506° Datum: NAD 1983
Date Started: 8/29/21 Date Completed: 8/30/21
Driller/Company: Aaron Devalle/Haztech Drill CS 1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: partly cloudy, 20's-30's F

Notes:
Purpose: East construction platform investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	N VALUE / PL WC LL / RQD (%) Recovery (%)
3600	30–31		30' to 35.5': PERLITE, black, fine grained, shiny appearance, homogenous to platy, with CLAY, high plasticity, and ICE crystals up to 1-inch long, Vx, clear, hard. Note: Due to low recovery in R7. PERLITE unit is inferred to extend to 35.5'. 30.5' to 31.7': SPT #06: N= 99/8". PERLITE with clay and ice as described above.	HQ3	SPT	S06	10-49-50/2" (4"=28%)			
	32–35.5		R7: RCT = 18 min. Note: Haztech reamed 4-inch diameter casing from 0' to 30.0' prior to drilling R7. Low core recovery. Recovered rhyolite gravel is inferred to be material that fell downhole during reaming and may not be representative of subsurface conditions. 35.5 ft	HQ3	Core	R7	Rec= 20% RQD=0%			
3595	35.5–38		35.5' to 42.5': Completely weathered, extremely weak (R0) rock. Some structure likely lost. [CLAY with sand, hard (PP > 4.5), light blue-grey to green-grey, moist, high plasticity, no dilatancy,with lenses of clayey sand (fine sand with high plasticity clay). With orange iron stained veins at 60 to 70 degrees from assumed horizontal.] R8: RCT=8 min.	HQ3	Core	R8 S1	Rec= 100% RQD=0%	Fines = 67.3%; nonplastic		
	38–40		R9: RCT=8 min.	HQ3	Core	R9	Rec= 100% RQD=0%			

BOREHOLE LOG PR21-07

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska
Surface Elevation: 3630.8 ft
Latitude: 63.53612° Longitude: -149.81506° Datum: NAD 1983
Date Started: 8/29/21 Date Completed: 8/30/21
Driller/Company: Aaron Devalle/Haztech Drill CS 1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: partly cloudy, 20's-30's F

Notes:
Purpose: East construction platform investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample No.	Core Rec., RQD, and Frac. Freq.	Test Results
3590	41	R10: RCT=6 min. With several mechanical breaks.	HQ3	R10	Rec= 100% RQD=0%	
	42	42.5 ft				
	43	42.5' to 47.3': RHYOLITE, fine grained, black to light grey to white flow banding, moderately weathered, weak (R2) rock, with perlite bands, with quartz and feldspar phenocrysts up to 0.25 inch. 42.5': Contact between rhyolite and clay is at 50 degrees from assumed horizontal.				
	44	R11: RCT=11 min Discontinuities are closely to moderately closely spaced, in poor to fair condition, at 10-40 degrees from assumed horizontal, with iron staining, trace clay and sand infilling, JRC's 4-10.		R11, UC1	Rec= 93% RQD=93% FF=1	UC = 9976 psi
3585	45–46	R12: RCT=17 min. Discontinuities are closely spaced, in very poor to fair condition, at 10-45 degrees and 70-80 degrees from assumed horizontal, with iron staining, trace clay infilling, JRC's 4-10.				
	47	47.3 ft				
	47.3	47.3' to 48.1': CLAY, green to grey, hard (PP>4.5), moist, high plasticity, no dilatancy. The upper and lower contacts occur along flow bands at 25 degrees from assumed horizontal.		R12	Rec= 97% RQD=20% FF=4	
	48	48.1 ft				
	49	48.1' to 50.5': RHYOLITE, fine grained, white to light grey, with flow bands from 0.04 to 0.2 inches at 25 to 45 degrees from assumed horizontal, discontinuities typically occur along iron stained flow bands.				

N VALUE 20 40 60 80; PL WC LL 20 40 60 80; RQD (%) Recovery (%) 20 40 60 80

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BOREHOLE LOG PR21-07

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska

Surface Elevation: 3630.8 ft
Latitude: 63.53612° Longitude: -149.81506° Datum: NAD 1983
Date Started: 8/29/21 Date Completed: 8/30/21
Driller/Company: Aaron Devalle/Haztech Drill CS 1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: partly cloudy, 20's-30's F

Notes:
Purpose: East construction platform investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	SAMPLE Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	● N VALUE 20 40 60 80 / PL WC LL 20 40 60 80 / RQD (%) Recovery (%) 20 40 60 80
			50.5 ft	HQ3						

Notes:

1) 50.5': End of Borehole.
2) Borehole backfilled with 5 bags (50 lbs.) of bentonite.
3) Field strength R values were assigned based on field observations of intact rock samples and assigned strength grades may not be equivalent to point load or unconfined compressive strength test results.
4) Completely to highly weathered material was dual classified with both rock and soil descriptions based on field observations. Field soil USCS classifications may not be consistent with grain size distribution and/or plasticity values from soil laboratory testing as difficulties in processing the soil-like weathered rock were reported to BGC by the lab.

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BOREHOLE LOG PR21-08

Project Name: Polychrome Area Improvements
Project Location: Denali National Park, Alaska
Surface Elevation: 3629.29 ft
Latitude: 63.53611° Longitude: -149.81465° Datum: NAD 1983
Date Started: 8/25/21 Date Completed: 8/28/21
Driller/Company: Aaron Devalle/Haztech Drill CS 1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: snow, high winds, 20's-30's F

Notes:
Purpose: East construction platform investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	SAMPLE Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	N VALUE (20 40 60 80) / PL WC LL (20 40 60 80) / RQD (%) Recovery (%) (20 40 60 80)
	0.0		0.0' to 12.5': Poorly graded GRAVEL with sand, medium dense, white to yellow, moist, medium to coarse, subangular to angular rhyolite gravel, some medium to coarse sand, trace clay, cobbles likely.	HQ3						
	1									
	2									
	3									
	4									
3625										
	5									
	5.0–6.5				Split spoon	S01	7-8-10 (6"=33%)			●
	6									
	7									
	8									
	9									
3620										

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
FEDERAL LANDS HIGHWAY DIVISION

BOREHOLE LOG PR21-08

Project Name: Polychrome Area Improvements | Sheet: 2 of 11
Project Location: Denali National Park, Alaska
Surface Elevation: 3629.29 ft
Latitude: 63.53611° Longitude: -149.81465° Datum: NAD 1983
Date Started: 8/25/21 Date Completed: 8/28/21
Driller/Company: Aaron Devalle/Haztech Drill CS 1000
Hammer Type: 140 lbs Cathead
Logger/Company: KTH/BGC
Weather: snow, high winds, 20's-30's F

Notes:
Purpose: East construction platform investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results
	11		HQ3	S02	7-7-22 (6"=33%)	
	12	12.5 ft				
	12.5	12.5' to 70.0': RHYOLITE, fine grained, red-yellow and light grey to white, slightly vesicular, moderately to slightly weathered, weak (R2) to strong (R4) rock, with flow banding, with red inclusions, and orange iron staining on discontinuity surfaces and iron infilled veins, some quartz phenocrysts.				
3615	14					
	15			S03	50/1" (1"=42%)	
	17	17.0' to 25.5': Moderately weathered, weak (R2) to medium strong (R3) rock. R1: RCT = 10 min. Discontinuities are closely spaced, in fair condition, at 20-30 degrees and 55-65 degrees from assumed horizontal, with iron staining, JRC's 14-16.				
	18.5	18.5' to 19.5': White, weak (R2) rock.		R1	Rec= 100% RQD=74% FF=3	
3610	19					

N VALUE ● (20, 40, 60, 80); PL WC LL (20, 40, 60, 80); RQD (%) / Recovery (%) (20, 40, 60, 80)

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Notes:
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See end of log notes.

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	N VALUE / PL WC LL / RQD (%) Recovery (%)
	21		R2: RCT = 12 min. Discontinuities are closely to moderately spaced, in fair to good condition, at 40-90 degrees from assumed horizontal, with iron staining, JRC's 10-12.	HQ3		UC1		UC = 7064 psi		
	22–25					R2	Rec= 82% RQD=43% FF=1			
3605										
	26–29		25.5' to 43.5': Slightly weathered, strong (R4) to very strong (R5) rock. R3: RCT = 13 min. 25.5'-27.0': Discontinuities are very closely to closely spaced, in poor to fair condition, at 25-65 degrees from assumed horizontal, with iron staining, and trace clayey sand infilling, JRC's 6-12. 27.0'-30.5': Discontinuities are moderately spaced, in good condition, at 60 degrees from assumed horizontal, with iron staining, JRC's 8-10.	HQ3		R3	Rec= 100% RQD=72% FF=2			
3600										

BOREHOLE LOG PR21-08

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Logger/Company: KTH/BGC
Weather: snow, high winds, 20's-30's F

Notes:
Purpose: East construction platform investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample No.	Core Rec., RQD, and Frac. Freq.	Test Results
			HQ3	UC2		UC = 5728 psi
	31	R4: RCT = 11 min. With flow banding. Discontinuities are closely to moderately spaced, in poor to good condition, at 20-50 degrees from assumed horizontal, with iron staining, trace clayey sand infilling on some, JRC's 8-12.	HQ3			
	32		HQ3	UC3		UC = 10230 psi
	33	33.0': Discontinuous lenses of white, high plasticity clay.	HQ3	R4	Rec= 100% RQD=77% FF=1	
3595	34–35		HQ3			
	36–38	R5: RCT = 13 min. Rhyolite as above with orange to brown cooling margins around phenocrysts. Discontinuities are closely spaced, in poor to good condition, at 10-90 degrees from assumed horizontal, with iron staining, and clayey sand infilling on some surfaces, JRC's 8-12.	HQ3	R5	Rec= 98% RQD=35% FF=3	
3590	39	39.3' to 40.5': Undulatory fracture at 70-90 degrees with 0.08 inch aperture, clayey sand infilling, JRC 10-12.	HQ3			

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Logger/Company: KTH/BGC
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Notes:
Purpose: East construction platform investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Sample Type	Sample No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	N VALUE (20 40 60 80); PL WC LL (20 40 60 80); RQD (%) / Recovery (%) (20 40 60 80)
	40.5–45.0		R6: RCT = 14 min. Discontinuities are very closely to closely spaced, in poor to fair condition, at 30-40 degrees and 70-80 degrees from assumed horizontal, with iron staining, and clayey sand infilling on some, JRC's 6-10. 43.5' to 45.5': Moderately weathered, very weak (R1) to weak (R2) rock, white, breaks down to clayey sand, fine sand, high plasticity clay, with gravel sized rhyolite.	HQ3		R6	Rec= 100% RQD=41% FF=2			
3585	44									
	45.0–48.0		45.5' to 70.0': Slightly weathered, medium strong (R3) to strong (R4) rock. R7: RCT = 7 min. Discontinuities are closely to moderately spaced, in good condition, at 30-70 degrees from assumed horizontal, with iron straining, and trace sand, JRC's 10-12.	HQ3		R7	Rec= 100% RQD=81% FF=2			
	47.1–48.0					UC4		UC = 18905 psi		
3580	48.0–50.0		R8: RCT = 6 min. Discontinuities are closely to moderately spaced, in good condition, in 30-40 degrees from assumed horizontal, with iron straining, JRC's 10-12.	HQ3		R8	Rec= 100% RQD=80% FF=2			

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Weather: snow, high winds, 20's-30's F

Notes:
Purpose: East construction platform investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	N VALUE / PL WC LL / RQD (%) Recovery (%)
	51		R9: RCT = 10 min. Discontinuities are closely to moderately spaced, in fair to good condition, at 40-90 degrees from assumed horizontal, with iron staining, JRC's 8-12.	HQ3						
	52									
	53					R9	Rec= 100% RQD=70% FF=2			
3575	54									
	55									
	56		R10: RCT = 9 min. Discontinuities are closely to moderately spaced, in very poor to good condition, at 40-50 degrees and 70-90 degrees from assumed horizontal, with iron staining, JRC's 10-14. 56.5' to 57.5': Undulating fracture at 70-90 degrees, brecciated, infilled with high plasticity clay and sand, JRC 10-12.							
	57					R10	Rec= 100% RQD=69% FF=2			
	58									
	59		R11: RCT = 6 min. No discontinuities. Flow banding is at 60 degrees from assumed horizontal with weak (R2) white bands up to 0.12 inches.							
3570						R11 UC5	Rec= 100% RQD=104% FF=0	UC = 10158 psi		>>

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Logger/Company: KTH/BGC
Weather: snow, high winds, 20's-30's F

Notes:
Purpose: East construction platform investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	N VALUE / PL WC LL / RQD (%) Recovery (%)
	61		R12: RCT = 14 min. Discontinuities are closely to moderately spaced, in poor to good condition, at 25-45 degrees and 70-80 degrees from assumed horizontal, with iron staining, trace clayey sand infilling, JRC's 8-12.	HQ3		R12	Rec= 98% RQD=73% FF=3			
3565	62–65									
	66		R13: RCT = 11 min. Rhyolite with white, black, red, and yellow flow bands up to 0.7 inches at 40-50 degrees from assumed horizontal. Discontinuities are closely spaced, in poor to good condition, at 40-50 degrees and 60-70 degrees from assumed horizontal, with iron staining, some orange high plasticity clay infilling, JRC's 4-12.			R13	Rec= 98% RQD=50% FF=4			
3560	67–69									
			70 ft							

BOREHOLE LOG PR21-08

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Logger/Company: KTH/BGC
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Notes:
Purpose: East construction platform investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Material Description	Drilling Method	Sample Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	RQD (%) / Recovery (%)
	70.0–70.5	70.0' to 70.5': CLAY with perlite gravel, yellow to brown, moist, high plasticity, no dilatancy, high toughness. (70.5 ft)	HQ3					
3555	70.5–77.5	70.5' to 77.5': PERLITE, black, fine grained, with trace obsidian corestones, moderately weathered, extremely weak (R0) to very weak (R1) rock, highly fractured. With clay, light green-grey, high plasticity, no dilatancy, with trace fine sand. R14: RCT = 15 min. Discontinuities are very closely to closely spaced, in very poor to poor condition, at 50-70 degrees from assumed horizontal, some structure lost, JRC's 14-16. R15: RCT= 14 min. Some structure likely lost. Several discontinuities in very poor condition, at 60-70 degrees from assumed horizontal, with clayey surfaces, JRC's 6-8. (77.5 ft)	HQ3		R14	Rec= 78% RQD=8% FF=6		
3550	77.5–80.5	77.5' to 80.5': Completely weathered, extremely weak (R0) rock. [Clayey SAND, light blue-grey, very dense, moist, fine sand, with some high plasticity clay, interbedded with fat clay, blue grey, hard (PP > 4.5), moist, high plasticity, no dilatancy, high toughness.]	HQ3		R15	Rec= 100% RQD=0%		

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Notes:
Purpose: East construction platform investigation.
See end of log notes.

Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	N VALUE / PL WC LL / RQD (%) Recovery (%)
			80.5 ft							
	81		80.5' to 85.7': Completely weathered, extremely weak (R0) rock. [CLAY, light blue-grey, hard (PP > 4.5), moist, high plasticity, no dilatancy, trace to some sand.] R16: RCT = 21 min. Structure likely lost.			S1		Fines = 4.5%; nonplastic		
	82									
	83					R16	Rec= 100% RQD=0%			
3545	84									
	85		85.7 ft	HQ3						
	86		85.7' to 90.5': Completely weathered, extremely weak (R0) to very weak (R1) rock, with remant flow banding and some perlite clasts. [Poorly graded SAND with clay and gravel, blue-grey to green-grey, very dense, moist, fine to coarse sand, some clay, fine perlite gravel, with some lenses of clayey sand.]							
	87									
	88		R17: RCT = 13 min. Some structure likely lost. Apparent discontinuities are in very poor condition, at 30-80 degrees from assumed horizontal, with clay surfaces, JRC's 6-8.			R17	Rec= 100% RQD=0%			
3540	89									

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Weather: snow, high winds, 20's-30's F

Notes:
Purpose: East construction platform investigation.
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Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	Type	No.	Field Blow Count (Recovery) / Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	N VALUE (20 40 60 80); PL WC LL (20 40 60 80); RQD (%) / Recovery (%) (20 40 60 80)
			90.5 ft	HQ3						
	91		90.5' to 100.0': Completely weathered, extremely weak (R0) rock, with some remnant flow banding. [CLAY with sand, hard (PP>4.5), light blue-grey to yellow with black perlite clasts up to 4 inches, moist, high plasticity, no dilatancy, some sand, some perlite gravel, structure mostly lost.]			S2		Fines = 16.%; nonplastic		
	92		R18: RCT = 14 min. Some structure likely lost. Apparent discontinuities are closely to moderately spaced, in very poor condition, at 20-50 degrees from assumed horizontal, with clay surfaces, and slickensides, JRC's 8-12.			R18	Rec= 100% RQD=0%			
3535	93–95		R19: RCT = 16 min. Structure likely lost. Apparent discontinuities are closely spaced, in very poor condition, at 20-40 degrees from assumed horizontal, with clay surfaces, and slickensides, JRC's 6-8.			R19	Rec= 96% RQD=0%			
3530	96–99		R20: RCT = 21 min. Structure likely lost.			R20	Rec= 96% RQD=0%			
			100 ft							

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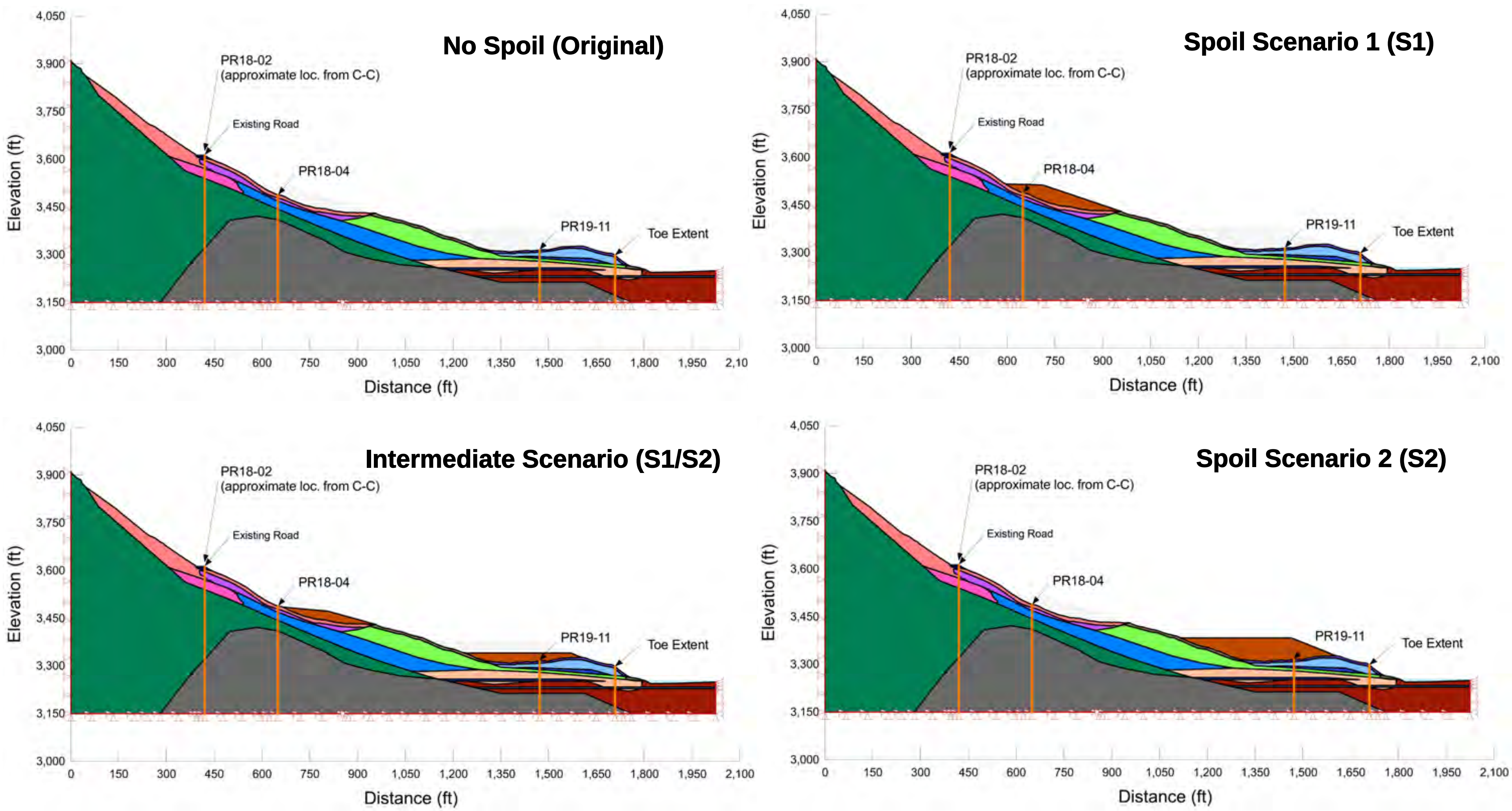
Elevation (ft)	Depth (ft)	Graphic Log	MATERIAL DESCRIPTION	Drilling Method	SAMPLE Type	No.	Field Blow Count (Recovery) Core Rec., RQD, and Frac. Freq.	Test Results	Install Details	● N VALUE 20 40 60 80; PL WC LL 20 40 60 80; RQD (%) Recovery (%) 20 40 60 80

Notes:

1) 100.0': End of Borehole.
2) Depth to water measured at 8.9' on 08-26-21 approximately 16 hours after drilling was stopped. Depth to water measured at 48.9' on 08-28-21, after Haztech completed drilling to 100.0' and approximately 1 hour after Haztech flushed the borehole with water. The depth to water continued to lower during televiewer surveys. Due to subsurface conditions and the use of drilling water, water levels may not be representative.
3) Downhole geophysical optical survey completed from approximately 22.0' to 57.0' and geophysical acoustic survey completed from approximately 53.0' to 71.0'.
4) Schedule 40 PVC (1-inch inner diameter) installed to 100.0'. The borehole was tremie grouted to the ground surface through 1-inch PVC with cement bentonite grout using approximately 170 gallons of grout on 08-28-21; surface grout return was not observed. Haztech added 50 gallons of grout on 08-29-21 at 7:00 PM and another 50 gallons of grout on 08-29-21 at 12:00 AM; surface grout return was not observed. Haztech reported that they believe grout loss was occurring between 20 and 50 feet below the ground surface. Haztech backfilled the borehole with approximately 8 bags (50 lb. bags) of bentonite chips.
5) VWP (S/N #2120914) installed at 99.0' on August 28,2021. A protection monument and VWP data logger were installed on September 2, 2021. The data logger was configured to a collection interval of 12 hours.
6) Field strength R values were assigned based on field observations of intact rock samples and assigned strength grades may not be equivalent to point load or unconfined compressive strength test results.
7) Completely to highly weathered material was dual classified with both rock and soil descriptions based on field observations. Field soil USCS classifications may not be consistent with grain size distribution and/or plasticity values from soil laboratory testing as difficulties in processing the soil-like weathered rock were reported to BGC by the lab.

APPENDIX B
SPOIL MODEL SECTION A-A RESULTS

03-2022



NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.

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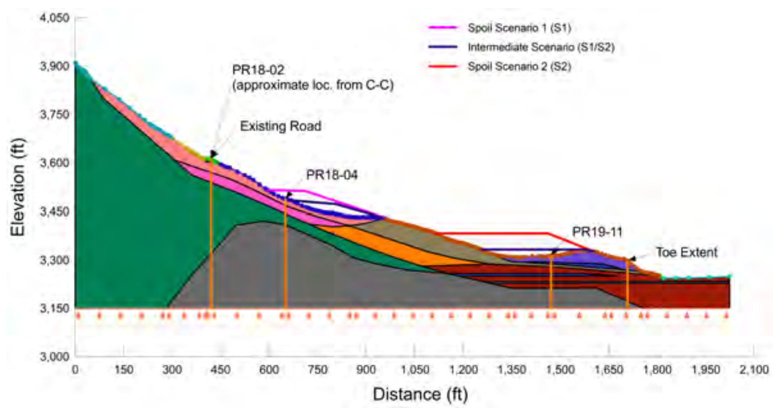
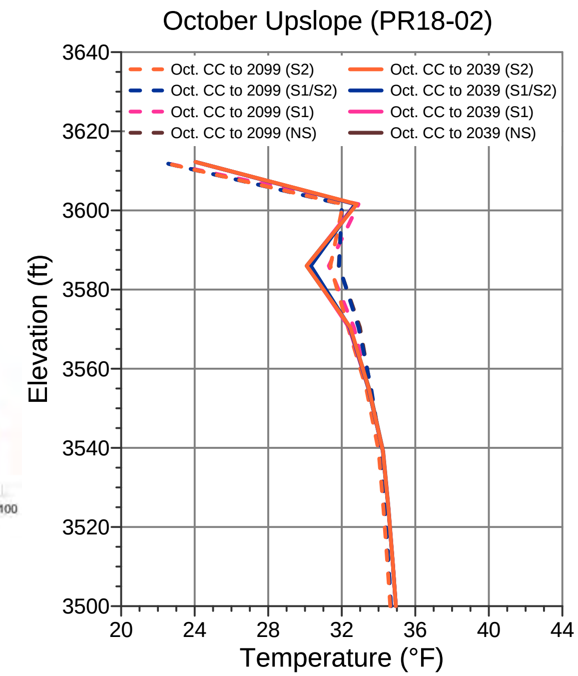
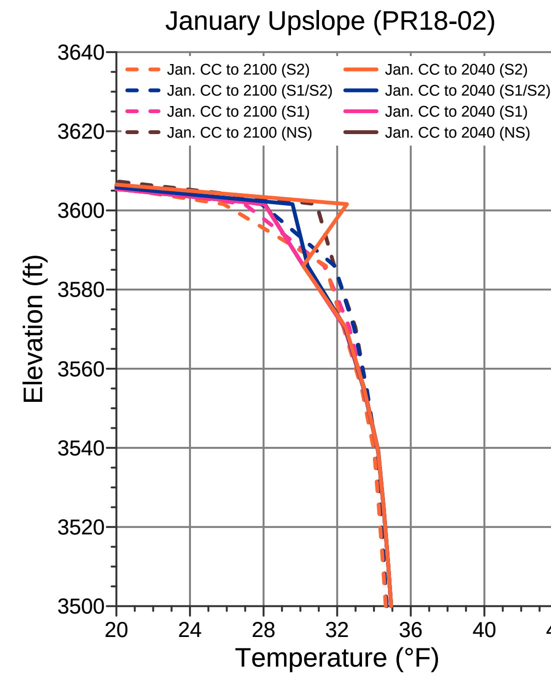
PREPARED BY: EDG	FIGURE TITLE: SPOIL PLACEMENT SCENARIOS FOR SECTION A-A		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: B-1

0 5 10 mm in ANSI A sized paper







NOTES:

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2. IN THE GRAPHS SHOWN, THE LABELS REFER TO THE MONTH (OCTOBER, JANUARY) AND CLIMATE CHANGE TIME SCALE WITH RESPECT TO THE DIFFERENT SPOIL SCENARIOS. FOR EXAMPLE, OCT. CC TO 2099 (S1) REFERS TO THE TEMPERATURE PROFILE WITH DEPTH OBTAINED IN THE MONTH OF OCTOBER 2099 FOR THE SPOIL SCENARIO S1.
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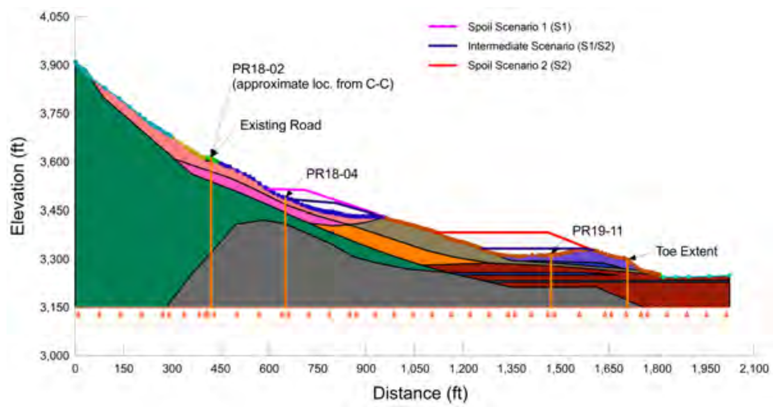
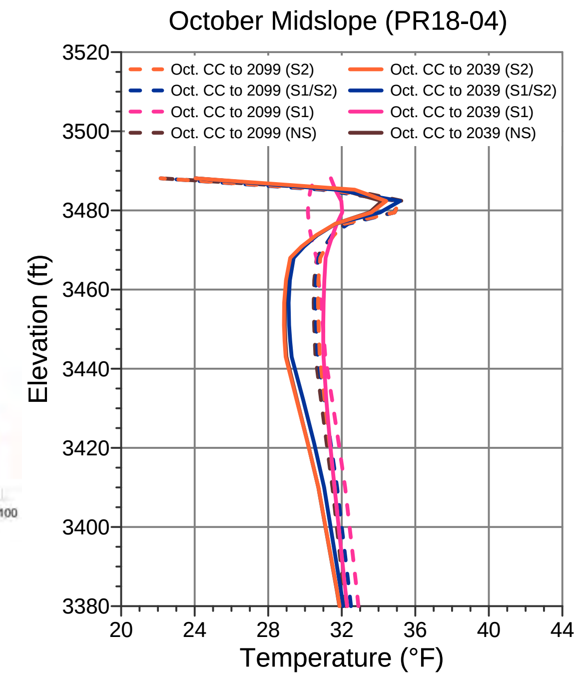
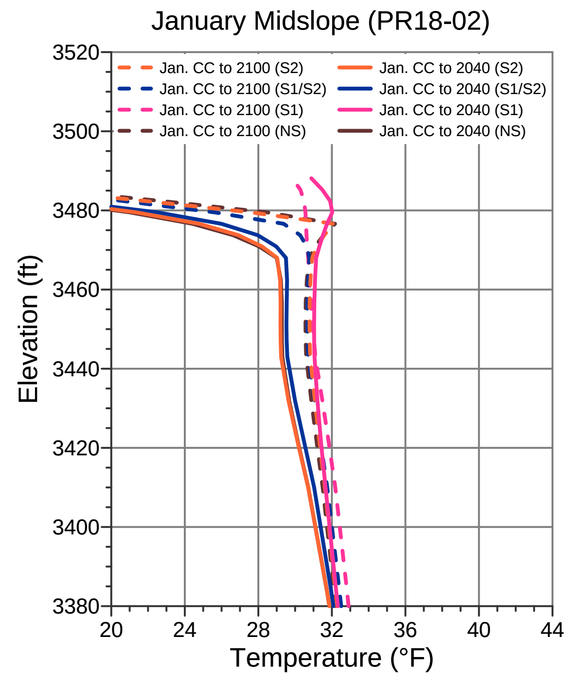
PREPARED BY: EDG	FIGURE TITLE: SECTION A-A SPOIL PLACEMENT RESULTS UPSLOPE LOCATION		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: B-2

0 5 10 mm in ANSI A sized paper

BGC ENGINEERING INC.







NOTES:
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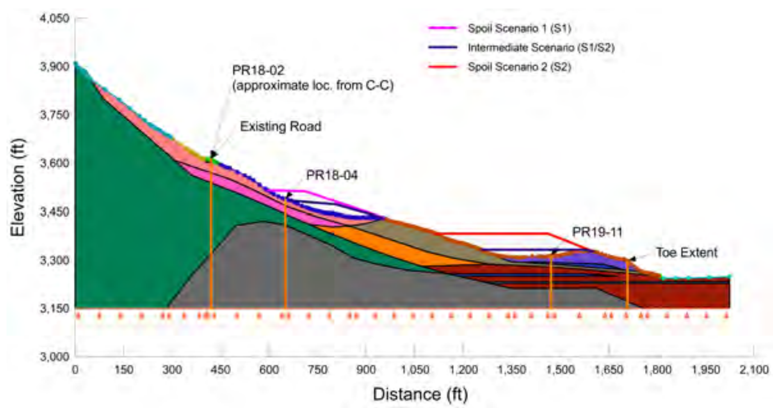
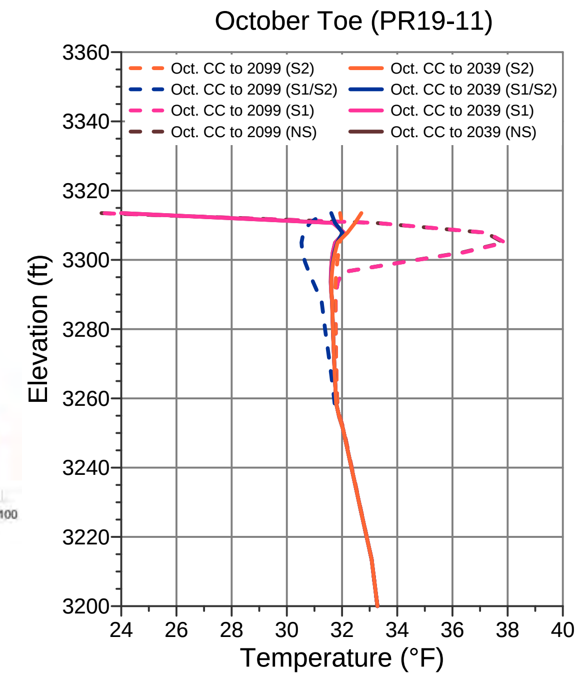
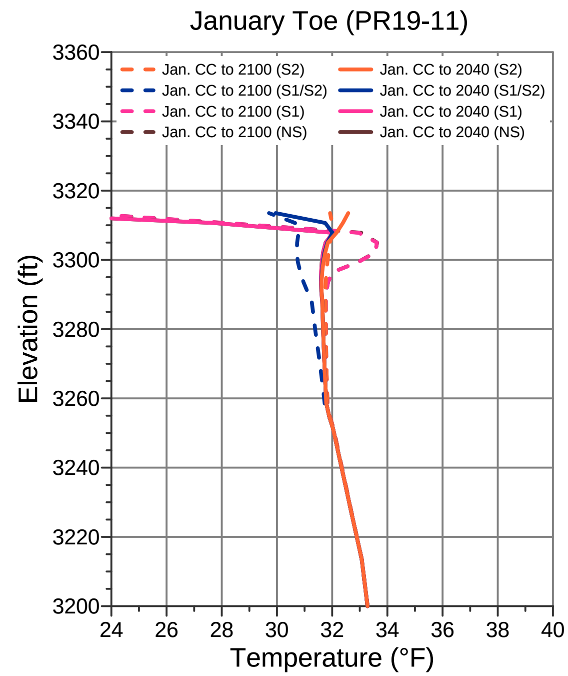
PREPARED BY: EDG	FIGURE TITLE: SECTION A-A SPOIL PLACEMENT RESULTS MIDSLOPE LOCATION		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: B-3

0 5 10 mm in ANSI A sized paper

BGC ENGINEERING INC.







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1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
2. IN THE GRAPHS SHOWN, THE LABELS REFER TO THE MONTH (OCTOBER, JANUARY) AND CLIMATE CHANGE TIME SCALE WITH RESPECT TO THE DIFFERENT SPOIL SCENARIOS. FOR EXAMPLE, OCT. CC TO 2099 (S1) REFERS TO THE TEMPERATURE PROFILE WITH DEPTH OBTAINED IN THE MONTH OF OCTOBER 2099 FOR THE SPOIL SCENARIO S1.
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PREPARED BY: EDG	FIGURE TITLE: SECTION A-A SPOIL PLACEMENT RESULTS TOE LOCATION		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: B-4

0 5 10 mm in ANSI A sized paper

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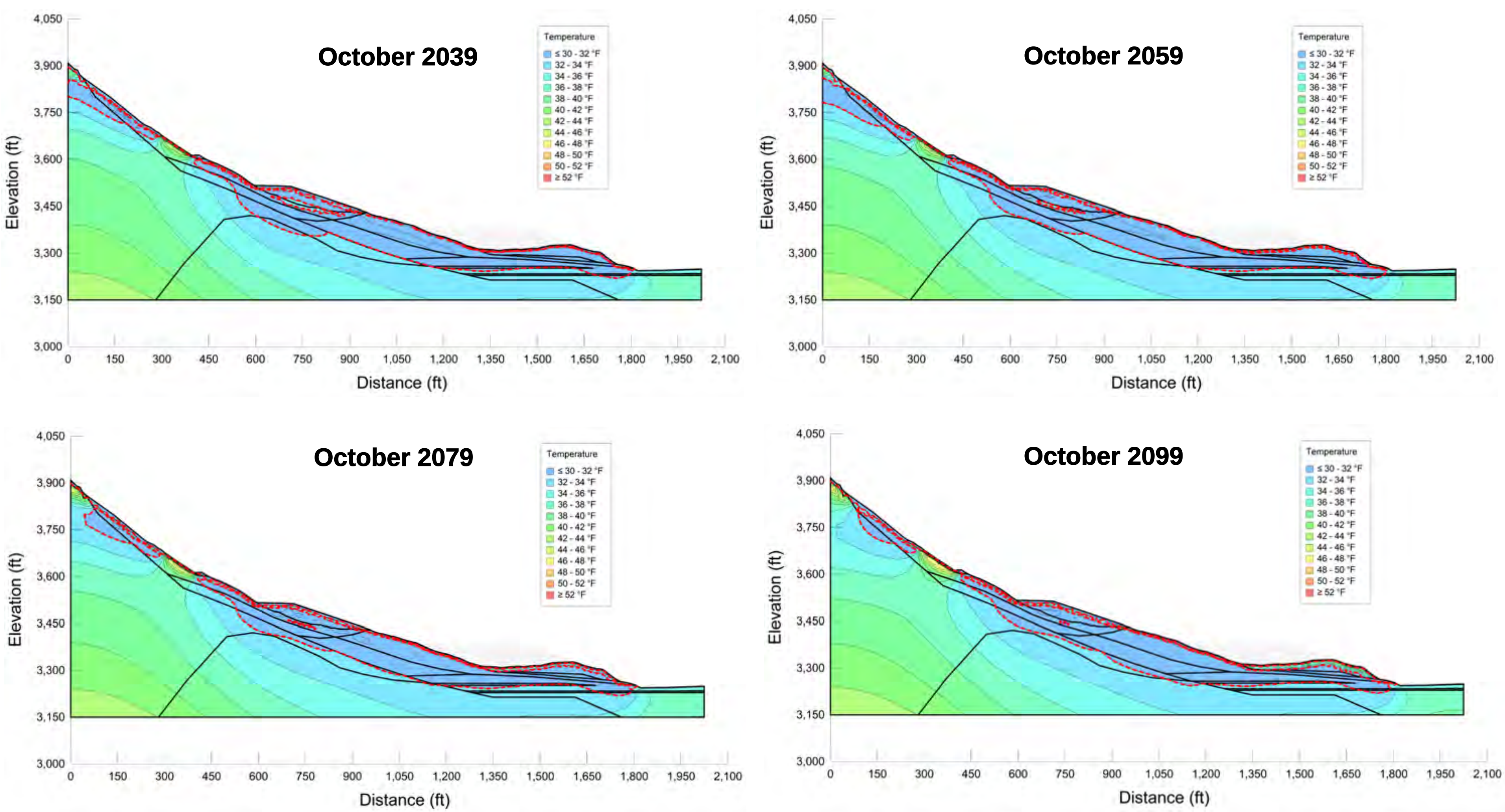

NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.

2. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

PREPARED BY:	FIGURE TITLE:		
EDG	ISOTHERM (OCTOBER) FOR S1 AT SECTION A-A		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: B-5

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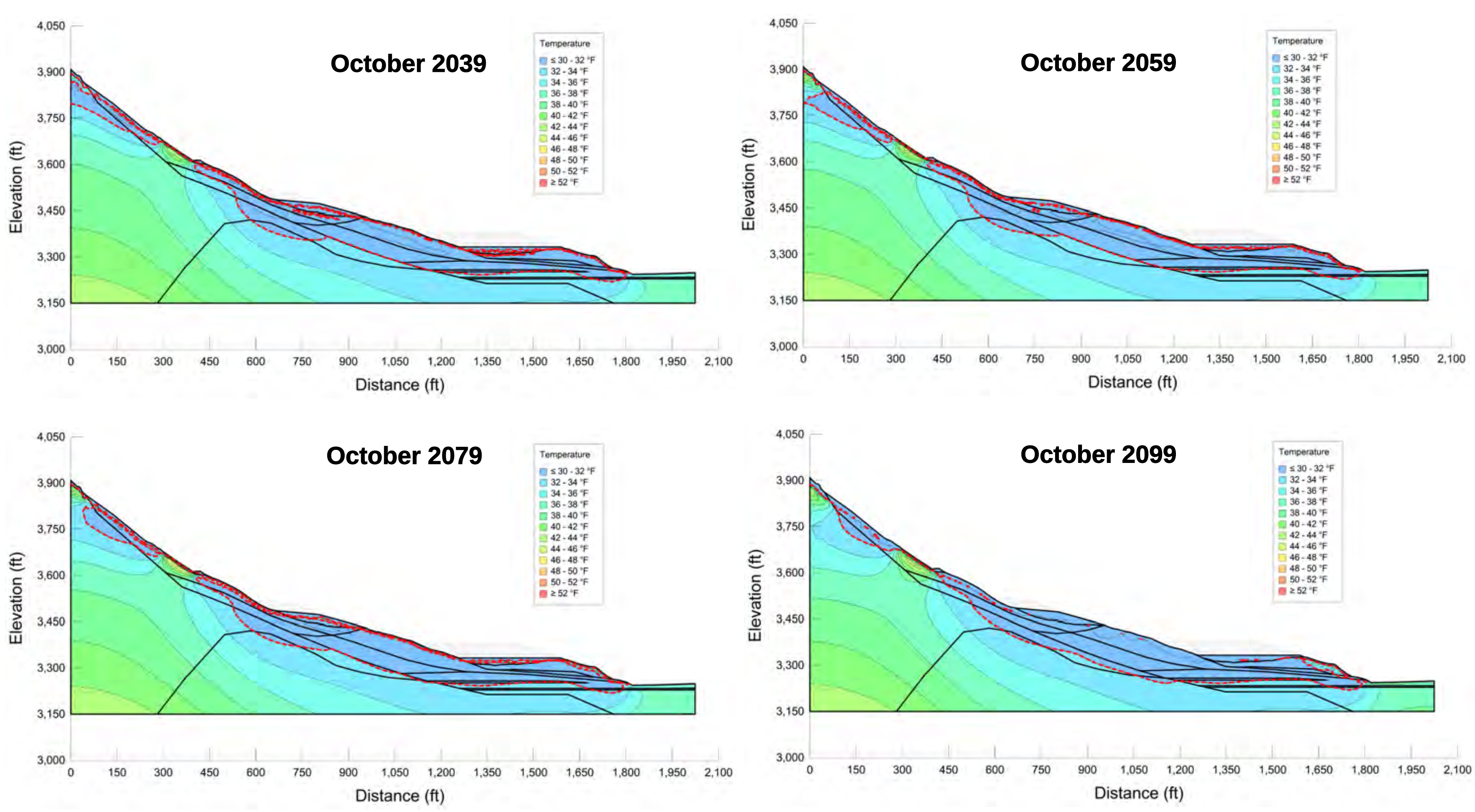

NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
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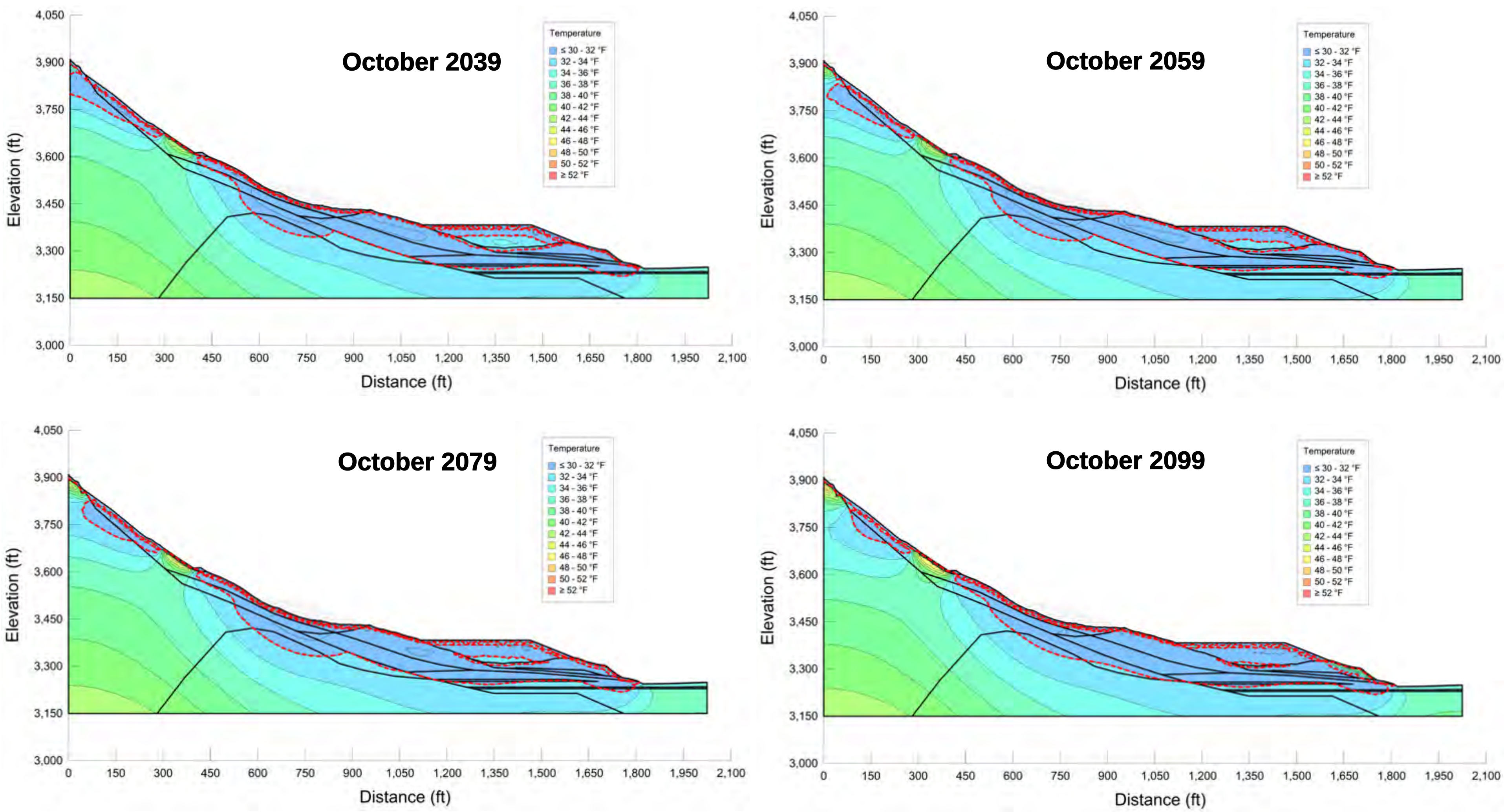
PREPARED BY: EDG	FIGURE TITLE: ISOTHERM (OCTOBER) FOR S1/S2 AT SECTION A-A		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: B-6

0 5 10 mm in ANSI A sized paper



NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
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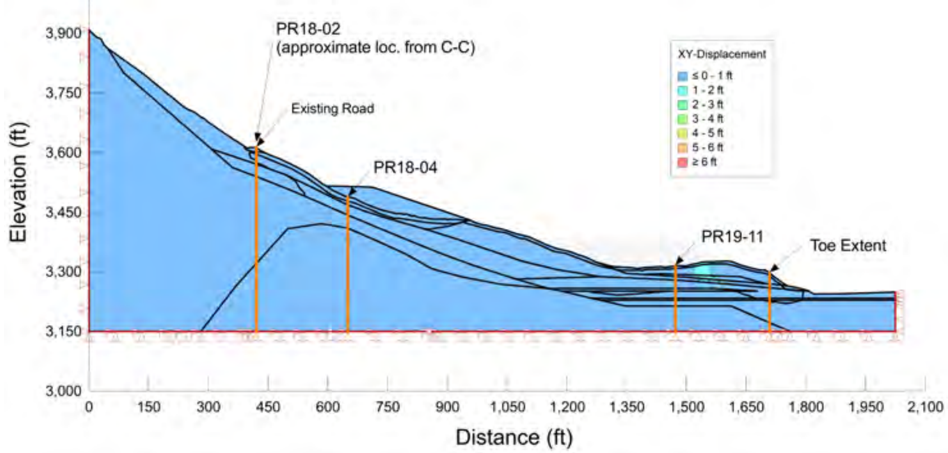
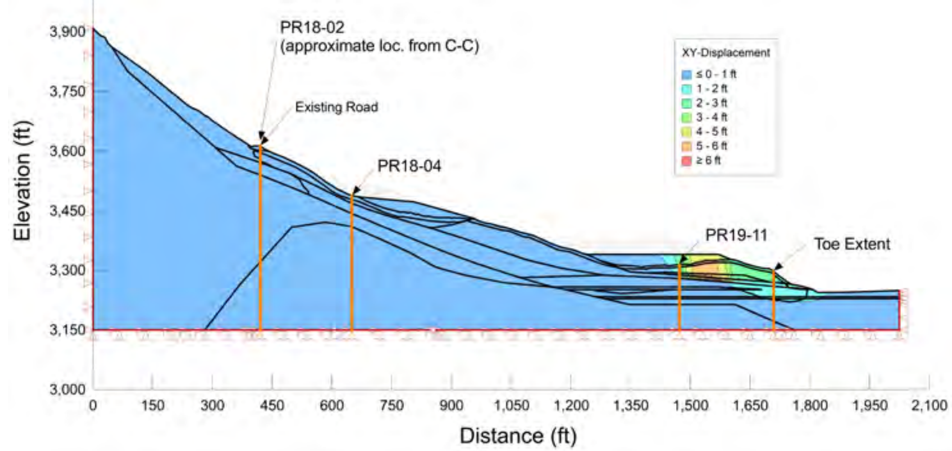
PREPARED BY:	FIGURE TITLE:		
EDG	ISOTHERM (OCTOBER) FOR S2 AT SECTION A-A		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: B-7

0 5 10 mm in ANSI A sized paper

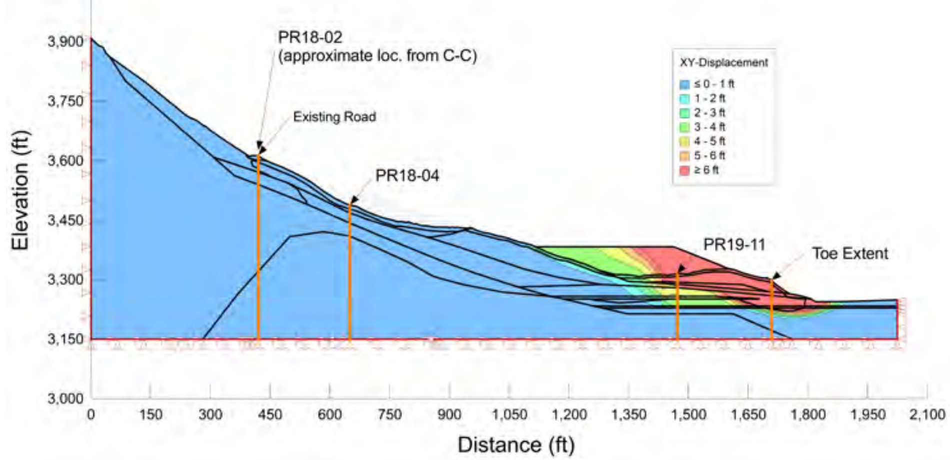
Spoil Scenario 1 (S1)



Intermediate Scenario (S1/S2)



Spoil Scenario 2 (S2)



NOTES:

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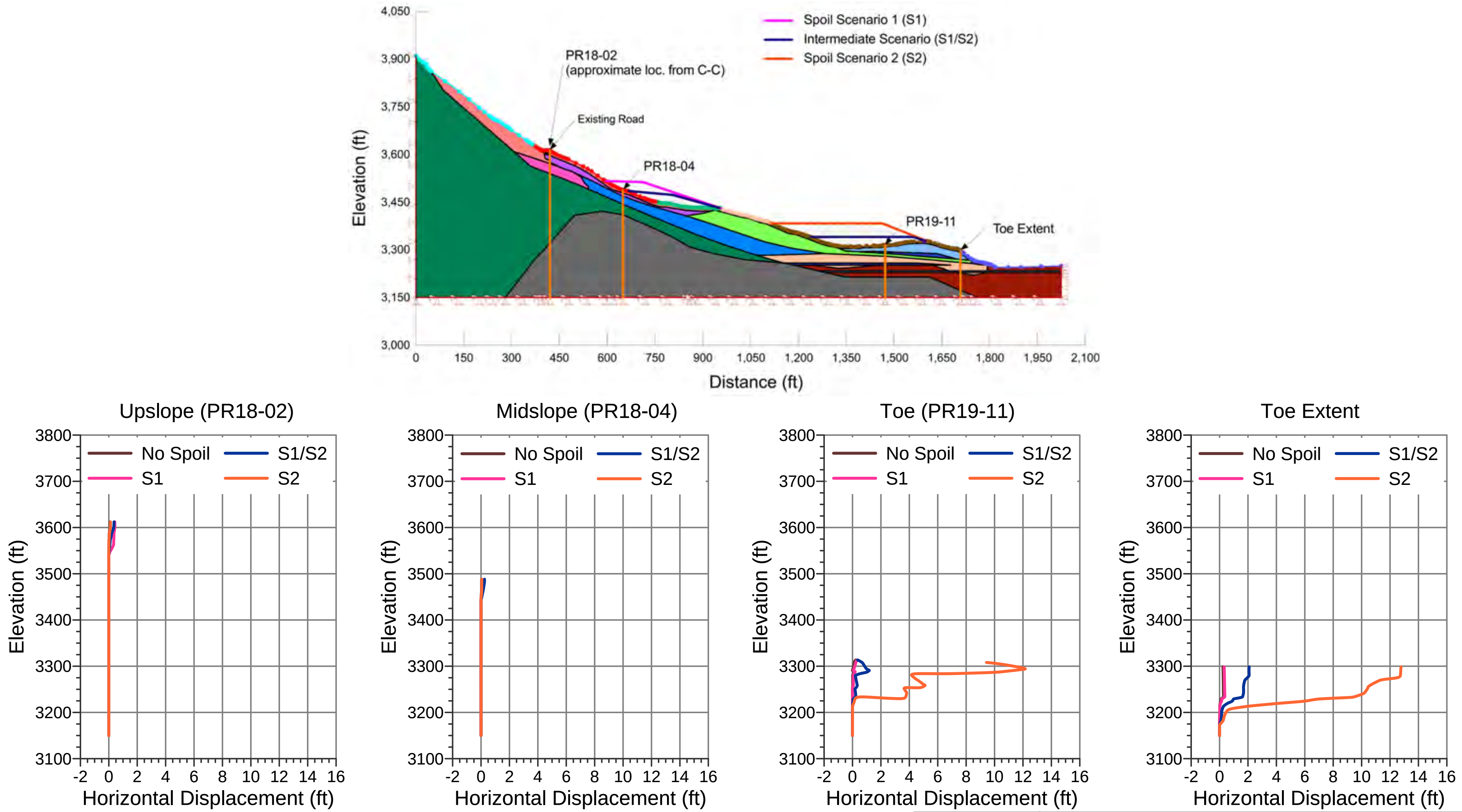
PREPARED BY: EDG	FIGURE TITLE: XY-DISPLACEMENT CONTOURS FOR SPOIL ADDED AT SECTION A-A		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: B-8

0 5 10 mm in ANSI A sized paper



NOTES:
1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
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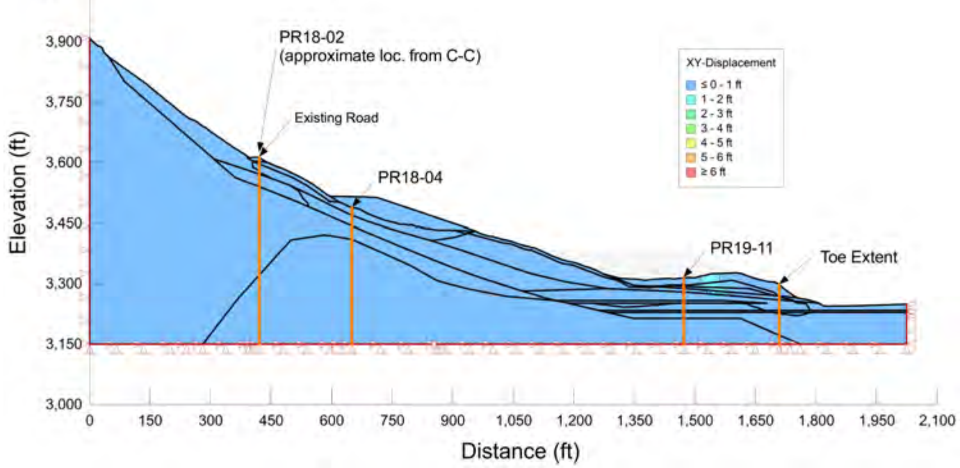
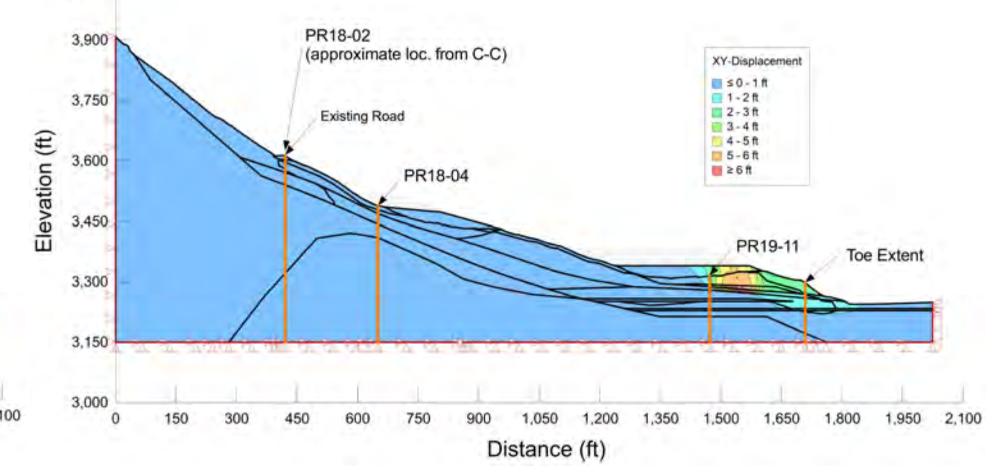
PREPARED BY: EDG	FIGURE TITLE: X-DISPLACEMENT W/ DEPTH FOR SPOIL ADDED AT SECTION A-A		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: B-9

0 5 10 mm in ANSI A sized paper

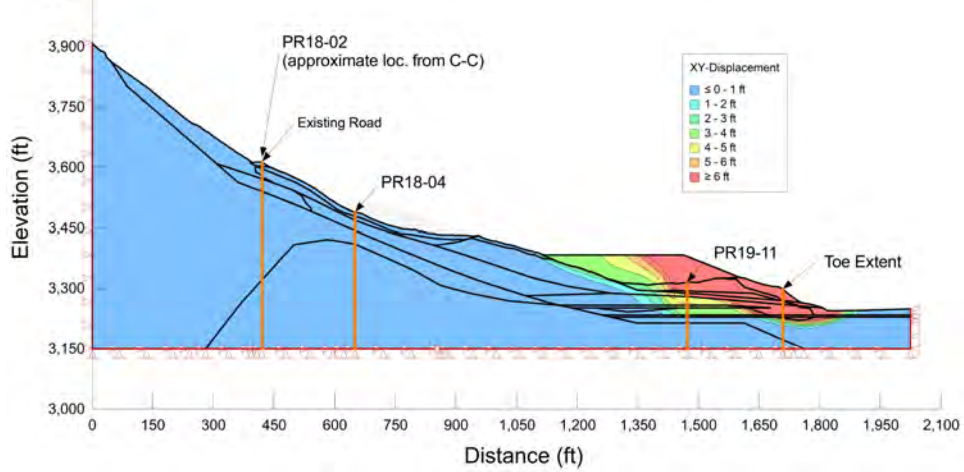
Spoil Scenario 1 (S1)



Intermediate Scenario (S1/S2)



Spoil Scenario 2 (S2)



NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
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PREPARED BY: EDG	FIGURE TITLE: XY-DISPLACEMENT CONTOURS AT YR 2100 AT SECTION A-A		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: B-10

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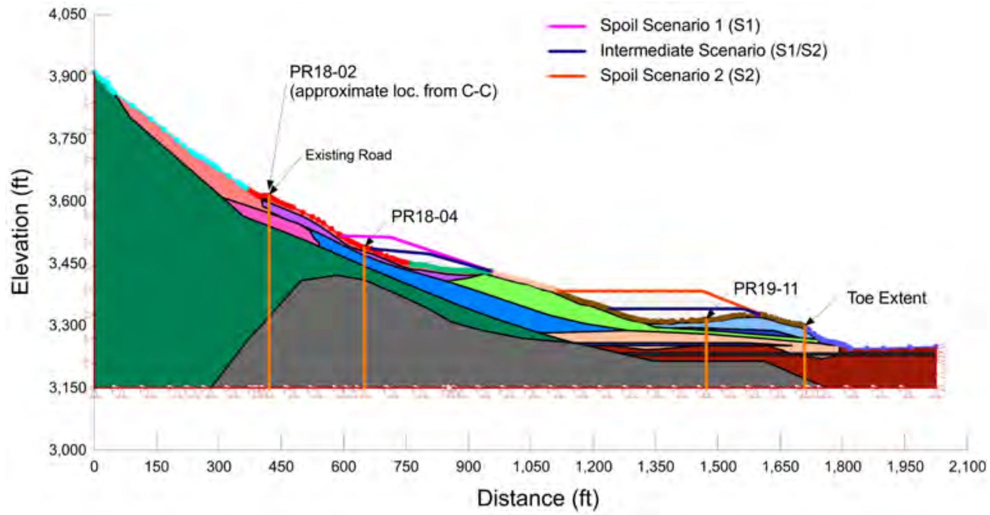

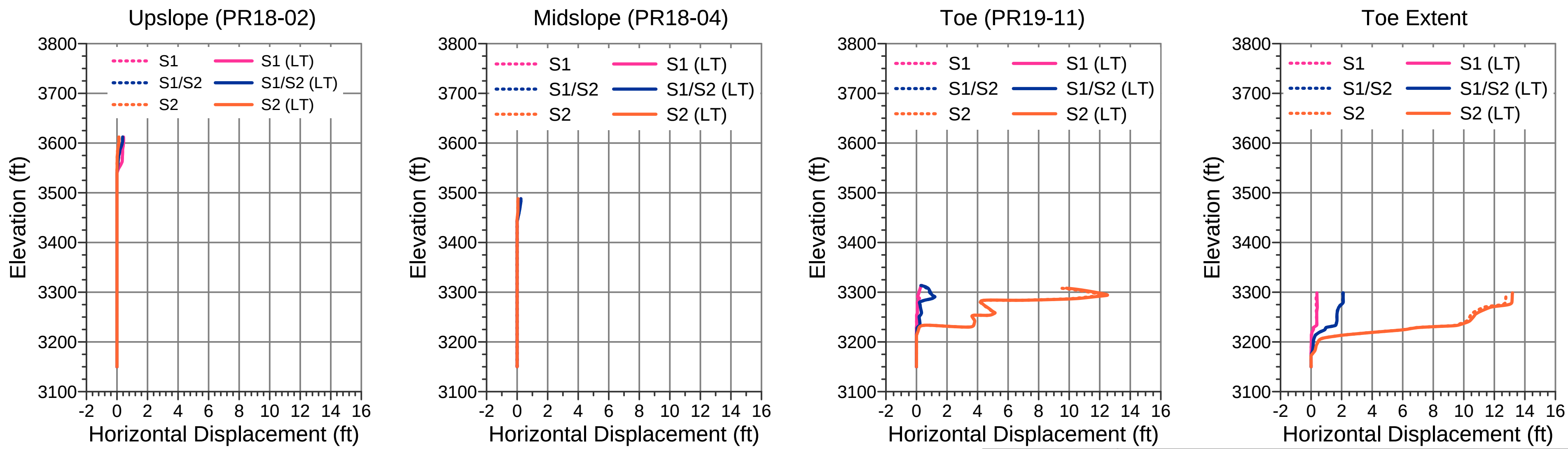

NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
2. IN THE GRAPHS SHOWN, THE SOLID LINES REFER TO THE LONG-TERM DISPLACEMENTS OBTAINED FOR CLIMATE CHANGE PROJECTION AT 2100. THE DASHED LINES REFER TO THE DISPLACEMENTS OBTAINED AT THE TIME OF SPOIL PLACEMENT.
3. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

PREPARED BY: EDG	FIGURE TITLE: X-DISPLACEMENT W/ DEPTH FOR YR 2100 AT SECTION A-A		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: B-11

0 5 10 mm in ANSI A sized paper

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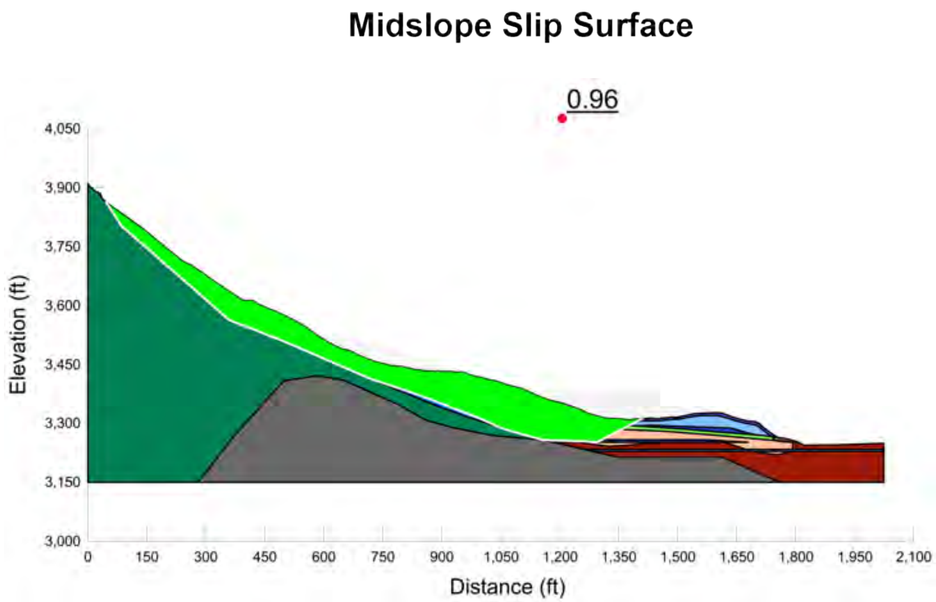

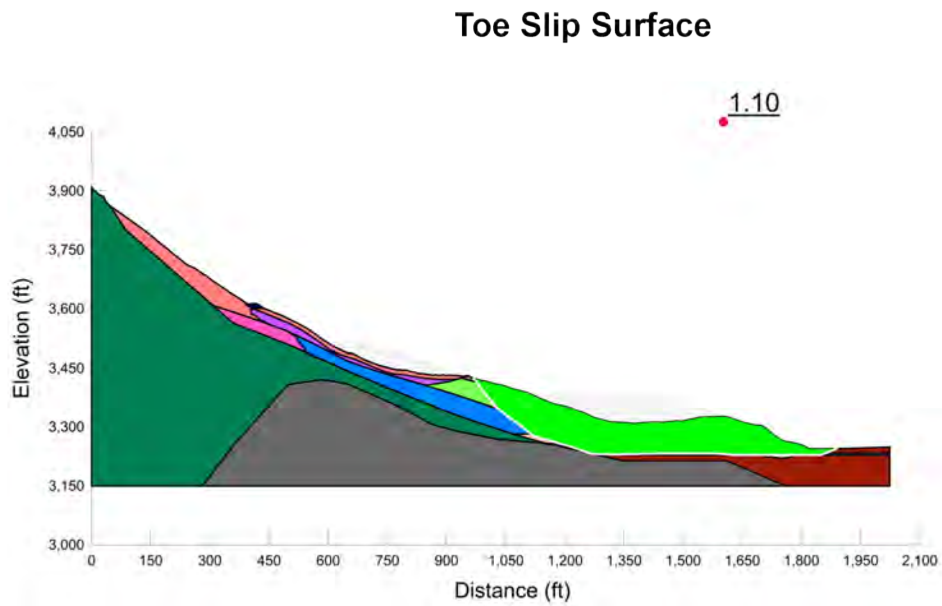

NOTES:

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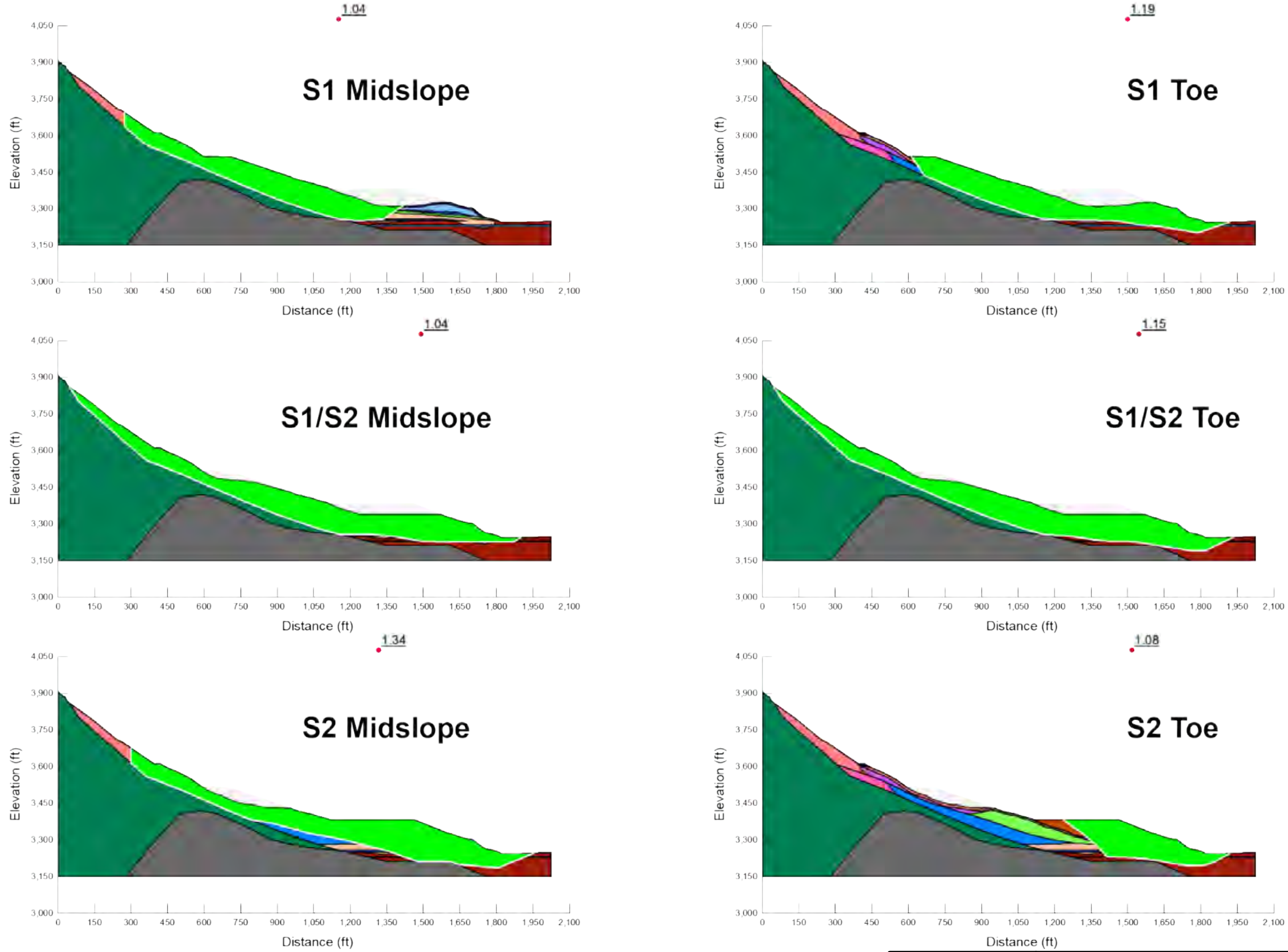
PREPARED BY:	FIGURE TITLE:		
EDG	FoS AND SLIP SURFACES FOR NO SPOIL CASE AT SECTION A-A		
CHECKED BY:	CLIENT:		
HMB	WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY:	SCALE:	PROJECT NO:	FIGURE NO:
LUA	NTS	2000004	B-12

0 5 10 mm in ANSI A sized paper

03-2022



NOTES:

1. THIS FIGURE SHOULD BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "POLYCHROME AREA IMPROVEMENTS - GEOTECHNICAL MODELING REPORT", AND DATED MARCH 29, 2022.
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PREPARED BY: EDG	FIGURE TITLE: FoS AND SLIP SURFACES W/ SPOIL ADDED AT SECTION A-A		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: B-13

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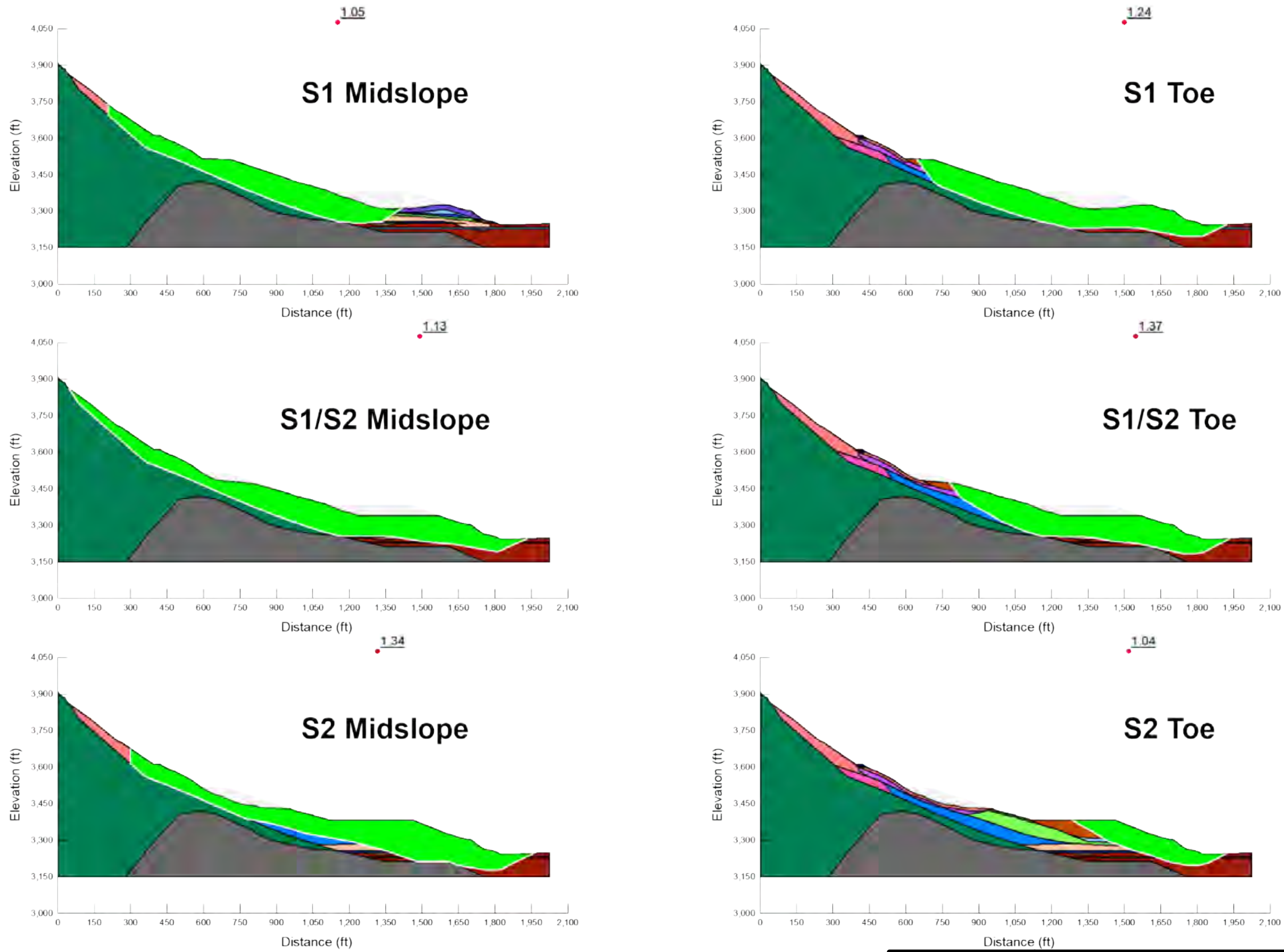

NOTES:

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PREPARED BY: EDG	FIGURE TITLE: FoS AND SLIP SURFACES FOR YR 2100 AT SECTION A-A		
CHECKED BY: HMB	CLIENT: WESTERN FEDERAL LANDS HIGHWAY DIVISION		
APPROVED BY: LUA	SCALE: NTS	PROJECT NO: 2000004	FIGURE NO: B-14

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